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Design of a

Reinforced-Concrete Highway Bridge

Civil Engineering

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**DESIGN OF
A REINFORCED-CONCRETE
HIGHWAY BRIDGE**

BY

HERBERT CHRISTIAN PETERSEN

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

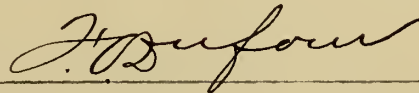
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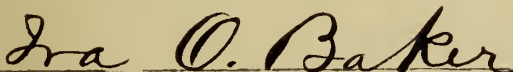
May 24, 1913.

I recommend that the thesis prepared under my supervision by HERBERT CHRISTIAN PETERSON entitled Design of a Reinforced-Concrete Highway Bridge be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.



Asst. Professor of Structural Eng'g.

Recommendation approved



Head of Department of
Civil Engineering.



DESIGN OF A REINFORCED-CONCRETE HIGHWAY BRIDGE.

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THE DESIGN OF A REINFORCED CONCRETE HIGHWAY BRIDGE.

I. Introduction.

There is probably no field of engineering which is so important to the welfare of society in general, as is highway engineering. In fact, the legislatures of most states have seen fit to provide a special corps of engineers to look after this most important of all methods of communication, namely, the public roads.

The application of scientific principles to the question of transportation and agriculture have practically replaced the old time horse drawn carts and light traction engines with immense automobile trucks and heavy tractors. As a natural consequence most of the old roads and especially bridges must be reconstructed. Such is the case in Champaign County, Illinois. It is the purpose of this thesis to investigate such an old bridge located about a mile northeast of Sidney, Illinois, and also to design a reinforced concrete bridge for the same location.



Fig. 1
General View of Old Spans.

The new span will be designed as a concrete structure; since it is possible to build a concrete bridge as cheaply as a steel one, and have in the end a more permanent and artistic structure.

II. THE OLD BRIDGE.

Art. I. Report.

The investigation of the old bridge will be presented in the form of an engineer's report; and since it is only incidental to the main purpose of this thesis, it will not be treated in a very exhaustive manner. The report is:

Champaign, Illinois,

February 22, 1913.

Chairman of Bridge Committee,

County Supervisors,

Champaign, Illinois.

Gentlemen:

Having thoroughly inspected and investigated the bridge over the Salt Fork Branch of the Vermilion River on the main highway between St. Joseph and Sidney, I submit the following report:

The bridge is located 1,320 feet east, and 400 feet south, of the west quarter point of Section 10, Township 18 North, Range 10 East. It consists of three steel spans.



*Fig 2.
View of Spans
Looking South*

The one to the south is a pony truss span of 28 feet, center to center of pins, and height 5 feet. The middle one is a pin connected pony truss span of 100 feet, center to center of supports, with upper chord curved to a parabola. The height at the middle is 9 feet. The span farthest north is a thru plate girder of 30 feet span over all. The clear roadway is 15 feet, the flooring is of wood, and the total overall length is 160 feet. The center line of the bridge is offset 2'9" at the south end, and 2'2" at the north end, east of the center line of the road.

The middle span or parabolic truss, as it will be termed in the following, is the oldest of the three spans. It was erected in 1867 by the King and Freese Manufacturing Company. The design was patented in 1861 by the same people. The other two spans are in the nature of approaches, and replaced former wooden trestle approaches. The steel approach, or girder span, at the north end was erected in 1894, while the pony truss approach at the south end was erected in 1898. The cost of the parabolic span was \$5,800, and each of the steel approaches cost \$466 with the necessary grading.

Description of Pony Truss.

The general appearance is very well shown in Fig. 3.



*Fig 3
Pony Truss
Span A*

The floor joists are 6-inch 12 1/4-pound I-beams spaced 26 inches on centers, and are 14 feet in length. The floor beams at the south end consist of two 8-inch 18-pound I-beams, one of which rests on the cast iron bents, while the other rests on the vertical I-beams which support the retaining walls. The middle floor beam is a fish bellied plate girder of 15 1/2 foot span. The depth at the middle is 18 inches, and at the ends 9 1/2 inches. The web plate is 1/4 inch thick and the flange angles are 3" x 2" x 1/4". The beam is supported by means of inverted loop rods 1 1/8 inches in diameter, which loop or hook over the pins and pass thru the ends of two small plates, one cast iron and one steel, and are fastened by nuts. The floor beam at the north end of the span is a 9-inch 2-pound I-beam of 14-foot span resting on top of the cast iron bent. The upper chord and end posts are made up members consisting of two 4-inch 6 1/4-pound channels with web verticals, flanges outstanding, and a plate 8" x 1/4" riveted to the top flanges. The lower flanges are tied together by batten plates. The middle vertical is of the same construction except that it has no cover plates. The diagonals consist of 2 3/4-inch round welded loop rods and the lower chord is of the same construction.

Description of Parabolic Truss.

The joists of this span are 5-inch 9 3/4-pound I-beams of lengths corresponding to the panel lengths which are variable. The floor beams are built-up members consisting of two 9-inch 13 1/4-pound channels with webs vertical and flanges outstanding.

The distance between webs is $2 \frac{3}{4}$ ". Two plates $10" \times 1 \frac{1}{4}" \times 11'0"$ are riveted to the top and bottom flanges. A width of the web, equal to $1 \frac{1}{4}"$, bears on a washer which rests upon the lower chord. The floor beam at the north end of the truss is common to both the girder and the parabolic truss, and is a 9-inch 25-pound I-beam. The upper chord is made up of two 6-inch 8-pound channels and two $10 \frac{1}{2}" \times 1 \frac{1}{4}"$ cover plates. The webs of the channels are horizontal and the flanges are outstanding. The verticals



Fig 4 Span B

are $1 \frac{1}{2}"$ round rods which pass thru a cast iron shoe and are fastened at both top and bottom with nuts. Thus the lower ends of the verticals support both the lower chord and the floor beams which rest on the lower chord. The diagonals and counters are round welded loop rods varying in diameter from $\frac{3}{4}"$ to $1 \frac{1}{8}"$. At the upper end the loops are horizontal and pass around the verticals. They are held from slipping down by a nut on the verticals. The lower ends pass thru the cast iron shoes just mentioned and are fastened by nuts. The lower chord is made up of two $4" \times 1 \frac{1}{2}"$ bars which are upset at each end to $1 \frac{1}{4}"$ in diameter. These upset ends pass thru the vertical backs of the shoes and are fastened by nuts.

Description of the Girder Span.

The floor joists are the same as in span A. The middle floor beam is constructed of a 9-inch 25-pound I-beam on top of

which rests an 8" x 3" plank, and on top of this is a 14-inch 6 1/4-pound I-beam. The floor beam at the north end is made up of a 9-inch 25-pound I-beam. Several pieces of 5-inch blocking resting on top of the I-beam carry an 8" x 6" timber 3" side vertical and a 3" plank. Both floor beams rest on the lower inside



Fig.5 Girder Span C.

flange angles of the girder which are inverted to form a shelf angle. The distance back to back of angles is 30 1/2". The web plate is 1/4" thick. The angles are 2 1/2" x 3" x 1/4". A railing consisting of channels and plates runs along the top of the girders.

TABLE I.
DETERMINATION OF WEIGHTS.
SPAN A (Pony Truss.)

UPPER CHORD AND END POSTS.

		Trusses			
Section	Size	Length	Wt. per ft.	Total Wt.	Gross Wt.
2 channels	4x1 5/8	31.83	6.25	297.5	
1 Plate	8x1/4	31.83	6.30	216.0	
12 Tie plates	4x1/4	0.66	3.40	27.2	
					640.7
		Verticals			
2 Channels	4x1 5/8	5.0	6.25	62.5	
6 Tie Plates	4 1/4x1/4	0.69	3.61	14.9	
					77.4
		Diagonals			
2 loop rods	1 5/16 Diam.	8.75	2.30	41.2	41.2
		Lower Chord			
4 loop rods	3/4" Diam.	14.0	1.50	34.0	34.0
		Pins			
5 Pins	1 7/8" Diam.	0.67	9.40	31.5	31.5
				Wt. of truss	874.8
				Wt. of 2 trusses	1749.6

FLOOR SYSTEM.

		Lateral bracing.			
4 rods	5/8" Diam.	22.86	1.04	91.0	91.0
		1 fish bellied floor beam			
1 Plate	14 1/2x1/4	15.50	14.38	220.0	
4 Angles	3x2x1/4	15.50	4.10	254.2	
					474.2
		Joists			
10 I-beams	6"	15.0	12.25	1840.0	
4 Channels	6"	15.0	8.0	480.0	
					2320.2
Total Wt. steel members					4634.8
Adding 10% for rivets & connections					463.5
Total Wt. of steel					5098.3

TABLE I (Continued)

Span A (Pony Truss)

FLOORING

Wt. of flooring	4050.0
Wt. of Railing	490.0
Wt. of felloe boards	450.0
Total Wt. of Wood flooring	<u>4990.0</u>
Total Wt. of Steel	5098.3
Total Wt. of Bridge	<u>10088.3</u>

TABLE I (Continued)
DETERMINATION OF WEIGHTS.
SPAN B (Parabolic truss)

TRUSSES.

Section	Size	Length	Wt. per ft.	Total Wt.	Gross Wt.
Upper Chord					
2 channels	6	103.5'	8.0	1656.0	
2 Plates	10 1/2 x 1/4	103.5	8.93	1848.0	
					3504.0
Verticals					
10 rods	1 1/2" Diam.	8.18	6.00	490.0	490.0
Diagonals					
2 rods	1 1/8 Diam.	6.2	3.38	41.9	
2 rods	1 Diam.	9.0	2.67	48.0	
2 rods	1/8 "	10.0	2.04	40.8	
14 rods	3/4 "	15.2	1.50	319.0	449.7
Lower Chord.					
2 bars	4 x 1/2"	100.5	6.80	1366.8	1366.8
				Wt. of 1 Truss	<u>5810.5</u>
					2
				Wt. of 2 Trusses	<u>11621.0</u>
WIND BRACING					
6 rods	1 1/2" Diam.	9.0	6.00	342.0	
3 Channels	6"	20.0	8.00	498.0	
					840.0
FLOOR SYSTEM.					
Joists					
5 I-beams	5"	100.5'	9.75	4899.4	
2 Channels	5"	100.5	6.50	1306.5	
					6205.9
Floor beams					
20 channels	9"	17.0	13.25	4500.0	
20 Plates	10" x 1/4"	11.0	8.50	1820.0	
					6220.0
Lateral bracing					
22 rods	7/8" Diam.	17.5	2.04	785.0	
10 rods	3/4" Diam.	23.5	1.50	367.0	
					<u>1152.0</u>

Total Wt. of steel members	26038.9
Adding 10% for rivets and connections	<u>2603.8</u>
	Total Wt. of steel
	<u>28642.7</u>
Weight of wood flooring	<u>17185.5</u>
	Total Wt. of bridge
	<u>45828.2</u>

TABLE I (Continued)
DETERMINATION OF WEIGHTS.

SPAN C
(Girder Span)

Section	Size	Length	Wt. per ft.	Total Wt.	Gross Wt.
Girders.					
1 plate	30"x1/4"	30.0'	25.5	765.0	
4 s	2 1/2x3x1/4	30.0'	4.5	540.0	
6 stiff. s	3x2x1/4	2.5'	4.1	61.5	
6 fill. pls.	2 1/2x1/4	2.16'	2.13	27.5	
4 end s	3x2x1/4	4.5	4.1	74.0	
2 plates	8x1/4"	2.0	6.8	<u>27.0</u>	1495.0
Railing					
1	5x1 3/4	30.0	6.5	195.0	
5 vert pls.	4x1/2	2.0	6.80	<u>68.0</u>	273.0
Wt. of girder & rail					<u>1758.0</u>
					2
Wt. of 2 girders & rails					<u>3516.0</u>

FLOOR SYSTEM.

Joists.					
5 I s	6"	31.0	12.25	1898.7	
2 s	6"	31	8.0	<u>496.0</u>	2394.7
Floor beam.					
1 I	9"x4 1/8	15.0	25.0	375.0	375.0
Lateral System.					
4 rods	1" ϕ	21.2	2.67	226.0	<u>226.0</u>
Wt. of steel members					<u>6511.7</u>
					651.
Total Wt. of steel =					<u>7162.7</u>
Wt. of Wood floor =					<u>4050.0</u>
Total Wt. of Span =					<u>11212.7</u>

TABLE II.
TABLE OF EFFICIENCIES.
SPAN A
(PONY TRUSS)

Member	Section	Direct Stress	Unit Stresses Actual	Allowable	Efficiency in %
Upper Chord	:2-4"-6 1/4" s. :1 Pl. 8x1/4"	: 34.17	: 11.25	: 16.00	: 70.3
End Posts	: " "	: 20.96	: 6.91	: 16.00	: 301.5
Floor beam (Middle)	:4-3x2" s. :1 Web Pl. 9"x10"x15'	:BM-937500	: 25.4	: 16.00	: 63.0
Floor beam (North end)	:1-9"- 25# I :15' -c.c. bear.	: " =776900	: 38.00	: 16.00	: 42.1
Joists	:6"-12 1/4" I s :14'-c.c. bear.	: " =287300	: 39.3	: 16.00	: 40.7
Diagonals	:2-7/8" ϕ loop rods	: 20.96	: 16.7	: 16.00	: 96.0
Lower Chord	:2-3/4 ϕ loop rods	: 17.13	: 19.4	: 16.00	: 82.5

NOTE - The efficiency of floor beam of south end of span was not determined. Because of the poor bearing which it has, its efficiency is practically zero.

TABLE II (Continued)

SPAN B (Parabolic truss).

Member	Section	Direct Stress	Unit Stresses		Efficiency.
			Actual	Allowable	
Upper Chord	2-6"-8" s 2-10"x1/4"c.pls.	133.37	29.14	16.00	55.0
Diagonals L.m	1-1 1/8" loop rod	5.9	7.79	16.00	206.0
" U.L ₂	1-1" ϕ " "	8.28	15.0	16.00	106.0
" U ₂ L ₁	1-7/8" ϕ " "	9.79	23.3	16.00	68.7%
" L ₅ U ₆	1-3/4 ϕ " "	15.88	52.6	16.00	30.4
Lower Chord	2-4"x1/2" bars flattened at ends to 1 1/2" ϕ	133.4	53.8	16.00	31.0
Verticals	1-1 1/2 ϕ rod	11.01	8.5	16.00	188%
Stringers	1-5"-9 3/4" I 12' - span	BM=244500	50.9	16.00	31.4
Floor Beam	2-9"-13 1/4" s 2-Pls.-10"x1/4"x 11'	886000	20.3	14.2	69.7
Floor beam North end	Same as North end Span A				

NOTE. Allowable stress in floor beam is 14.2 because it was taken in proportion to net area as the plates are riveted to flanges.

TABLE II (Continued)

SPAN C

(Girder Span)

Member	Section	Direct Stress	Unit Stresses		Effi- ciency
			Actual	Allowable	
Girder	1-pl.-30"x1/4' 4 s 3"x2 1/2"x1/4"	89.5	27.9	16.00	57.4
Joists	1-6"-12 1/4# I 15' span	BM.=309,450	42.4	16.00	37.6
Floor Beam	1-4"-7 1/2# I 1-9"-25# I 1-8"x3" plank	386,000=BM.	27.4	16.00	58.4

Investigation.

The main members were investigated in the usual manner and the results are tabulated in Table II. A glance at the table will indicate that the efficiencies of the main members are far below 100 per cent in nearly all cases. Hence it was thot unnecessary to investigate the connections. Their general condition will however be commented upon.

In investigating the members, Ostrup's Specifications were followed thruout, with the exception of the engine loading.

The dead panel loads were determined by computing the weights of the spans from the data taken in the field. The weights are tabulated in Table I. The live uniform load was assumed to be 80 pounds per square foot. The engine load was considered to be that of a 15-ton traction engine of which 10 tons were assumed to come on the rear axle and 5 tons on the forward axle. The distance center to center of axles is 10 feet. The gauge is 6 feet.

General Condition.

The general condition of the bridge is alone enough to warrant its replacement by a new span. In the first place carelessness or ignorance in erection and design are everywhere apparent. This is probably due to the fact that at the time this bridge was designed and erected very little was known about how the stresses in a bridge act. This is very clearly shown by the fact that the cross section of the diagonals and counters decrease in section as they go out from the middle, while the stresses in these members increase as they go out from the middle.

This plainly shows that stresses were probably never calculated; but were assumed to act as they do in a pratt truss, namely, get smaller as they approach the middle.

The carelessness in erection is brought out by the fact that whenever it was a little difficult to drive a rivet, the rivet was omitted. This is especially true in the upper chord at the verticals where it was hard to back the rivet up.

All the steel work is badly rusted, especially the floor joists and beams.

The rivets in the parabolic truss are all hand driven and the work was poorly done. A great many of them are loose and the heads badly shaped and distorted.

The bearing of most of the members on their supports is very deficient. The resting of floor beams on narrow washers, on 1 1/2" unsupported round rods of the lower chords, and on one edge, is quite a dangerous procedure. Fig. 6 and 7 show the way the north end floor beam of the parabolic truss rests on the lower chord, and how the intermediate floor beams rest on washers.

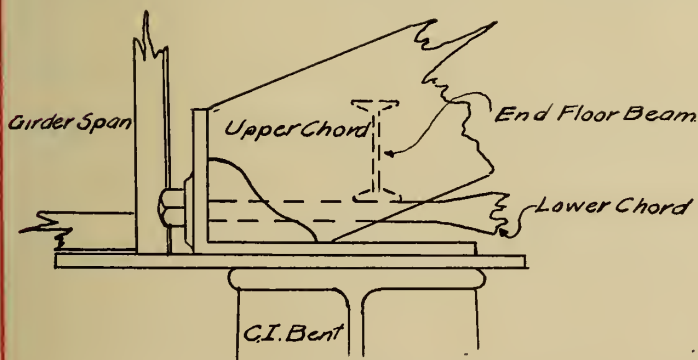


Fig. 6

Showing End Floor Beam Support

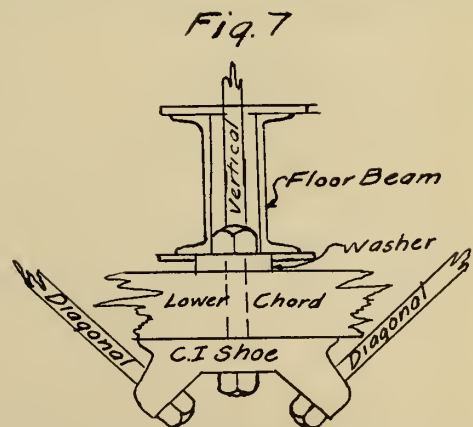


Fig. 7

Intermediate Floor Beam Support.

These are only a few of a great number of faulty details.

The welds in general are very poor; a number of them could have been pried open with a screw driver.

The field connections of all the spans were bolted and not riveted as they should be.

All three spans are greatly lacking in rigidity, particularly the parabolic truss. A light load such as a horse and buggy causes the upper chord to sway and vibrate considerably both in a horizontal and vertical plane. The diagonals and counters also vibrate and rattle when a load passes over the bridge.

Abutments.

The abutment at the south end consists of a cast iron bent as shown in Fig. 3. A retaining wall consisting of slabs of concrete $3\frac{1}{2}' \times 3' \times 2'$, held in place by vertical I-beams, holds back the earth. The end floor beam which consists of two I-beams, one of which rests on the tops of the bents while the other, or inside one, rests on the top of the vertical I-beams. The earth fill has pushed the wall out about 8" so that the floor beam which rests on the bents is entirely free of the joists, while the one which rests on the beams is tilted so that it rests on an edge of the flange. The abutment at the north end consists of a vertical steel plate which holds back the earth, and two built-up columns driven into the ground, which support the flanges of the girder.

One of the cast iron bents has been cracked off and repaired as is very well shown in Fig. 3. The standard opposite this is cracked where the horizontal plate is bolted onto the legs. It has not been repaired.



Fig. 8
View Showing Fractured Bent.

Conclusion.

A bridge in the condition as described, and with members whose efficiencies are as low as shown, is a great danger and menace to the public; and the writer hereby condemns the bridge as unsafe, and recommends that it be barred to prevent traffic.

Very truly yours,

H. C. Petersen.

Consulting Engineer.

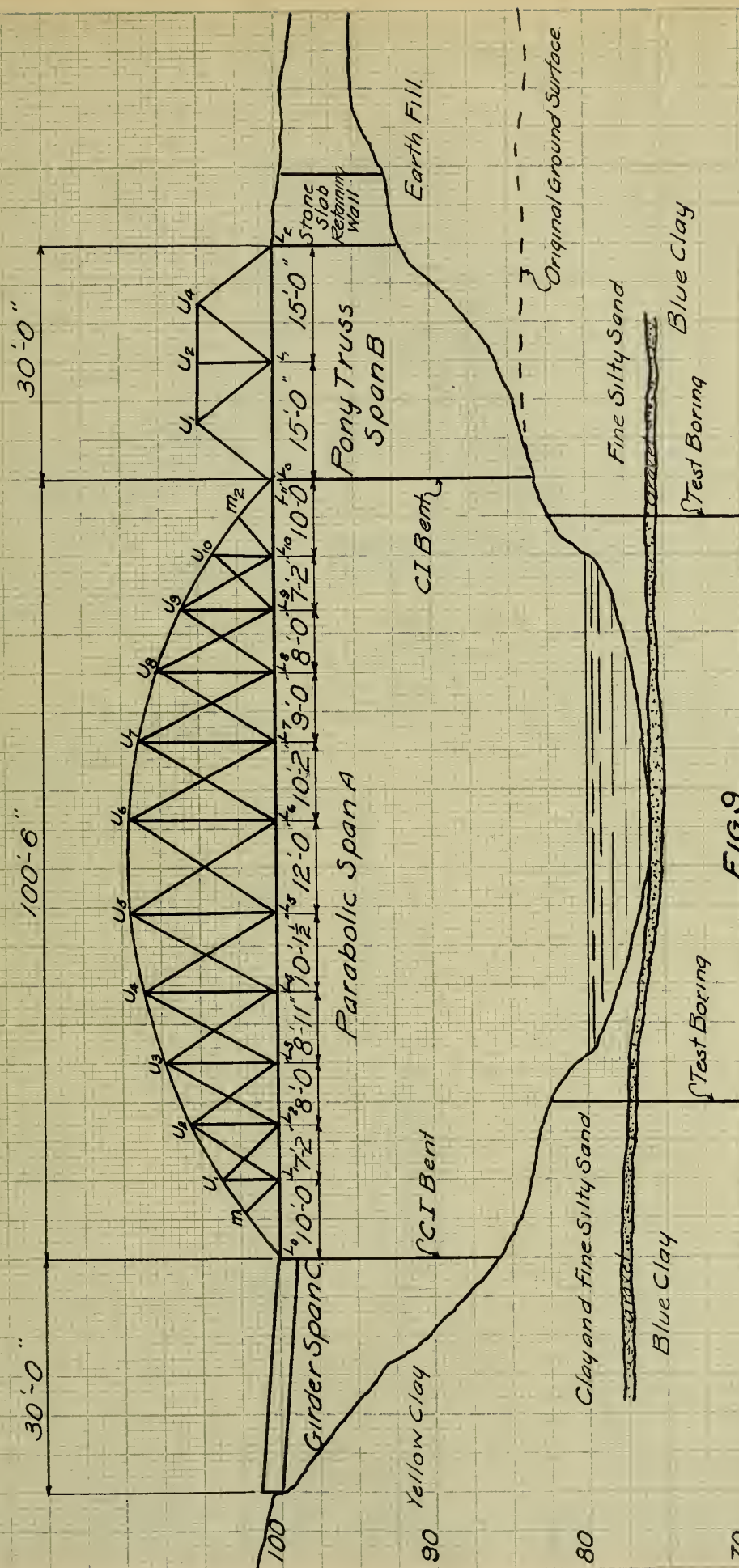
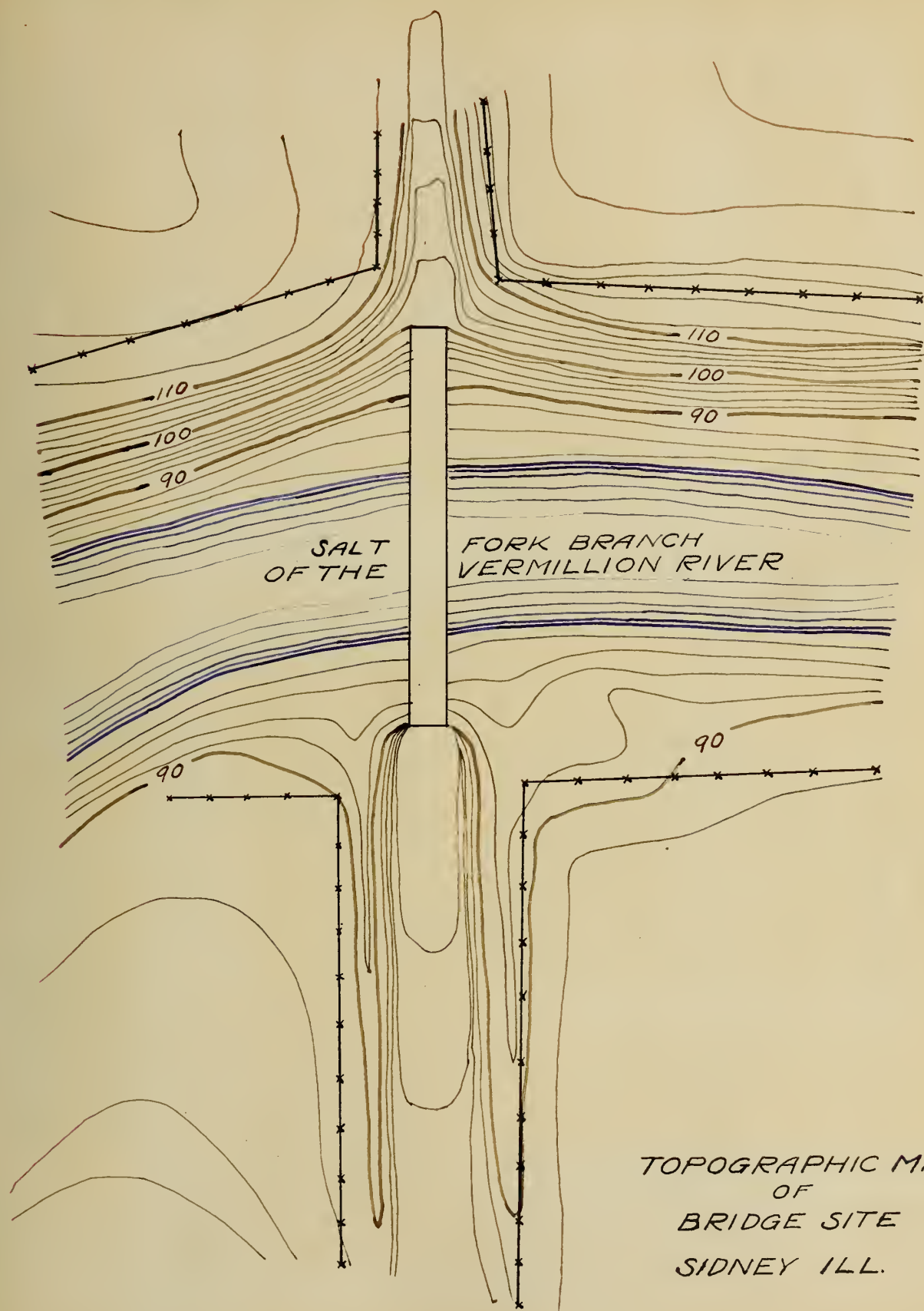


FIG. 9
 PROFILE OF BRIDGE SITE
 SHOWING OLD SPANS
 Vertical Scale 1"=20' Horizontal Scale 1"=10'



TOPOGRAPHIC MAP
OF
BRIDGE SITE
SIDNEY ILL.

Fig. 10

III. THE NEW BRIDGE.

Art. 2 - Survey of Site.

In order to intelligently design a bridge for a certain location, it is essential to have at hand a topographical map of the territory immediately surrounding the proposed bridge.

Since the new bridge will replace the old one, the center line of the new bridge will coincide with the center line of the road. Topography was taken with a transit and level rod, using as a base line, the center line of the road, established with respect to the fences. The elevation of the floor of the old bridge was arbitrarily taken as 100, and all other elevations were referred to this. A profile of the center line of the road and the topographic map are shown in Fig. 9 and 10 respectively.

Art. 3. Determination of Class of Bridge.

There are two general classes of reinforced concrete highway bridges, namely, the arch type and the girder type. The latter class may again be subdivided into the through and deck girder types. For bridges up to 160 feet in length the girder bridges are more economical than arch bridges. Since low cost is the governing factor in this design, a deck girder bridge was decided upon.

The largest vehicles likely to pass each other on the bridge simultaneously would be two automobiles. A 16-foot roadway would amply provide for this contingency.

The total overall length of the old bridge is 160 feet. There are no evidences of scour nor of the washing out of the

road back of the abutments; hence it will be appropriate and safe to make the overall length of the new bridge 159 feet. It has been found uneconomical to build girder bridges in spans greater than 60 feet. This necessitates that this bridge be built in three spans of 53 feet each, and it will therefore involve the construction of two piers. To eliminate a great deal of grading, the bottom of the floor slab of the new bridge will be laid at the same elevation as the floor of the old bridge.

Art. 4. Loadings.

It is necessary before assuming the loadings for a bridge design to know something about the traffic. Altho this bridge will be on a main thoroughfare, the traffic is comparatively light. The heaviest vehicle in the vicinity is a 23,000-pound traction engine, and it is not probable that heavier engines will come into use because of the difficulty experienced in traveling on the soft roads in wet weather. It will therefore be safe in this design to assume a live load produced by a 15-ton engine. The heaviest uniform live load would be that brought on the bridge by driving a herd of cattle over it. This would be equivalent to about 85 pounds per square foot.

Art. 5. Contract and Specifications.

Advertisement for Bids.

Sealed bids will be received till noon at the County Clerk's Office, County Court House, Urbana, Illinois, for the removal of old spans and the building of a reinforced concrete deck girder highway bridge of 159 feet overall span over the Salt Fork branch of the Vermilion River, about one mile north east of Sidney,

Illinois. All bids must be accompanied by a certified check for the sum of \$500. Plans and specifications are on file at the County Clerk's Office, County Court House, Urbana, Illinois. The county supervisors reserve the right to reject any or all bids.

Instructions to Bidders.

1. Bidders are urgently requested to read this contract and specifications and to thoroughly examine the proposed bridge site. They should also satisfy themselves as to the correctness of the estimate of quantities.

2. Each bid must be enclosed in a sealed envelope and addressed as follows.

County Supervisors Champaign County,
Care of County Clerk,
County Court House,
Urbana, Illinois.

Bids for the removal of old spans and the construction of a reinforced concrete highway bridge near Sidney, Illinois.

3. Any bid not accompanied by a certified check for the sum of \$500 will be rejected.

4. If required, bidders must give satisfactory evidence that they are reasonably experienced in reinforced concrete bridge work, and are thoroughly competent to carry out this contract.

5. The County Supervisors reserve the right to reject any or all bids.

Contract.

This agreement made and concluded this _____ day
of _____, 1913, between the County of _____

Illinois, by _____ Supervisor, _____
 Supervisor, _____ Supervisor, heretofore appointed
 by the direction of the Board of Supervisors to represent said
 county in the matter of said bridge, and the Commissioners of High-
 ways of the town of _____ in the County of _____
 Illinois, _____ Commissioner, _____
 Commissioner, _____ Commissioner, acting jointly
 and known as the party of the first part, and _____
 _____, his heirs, executors, successors, or assigns
 known as the Contractor, party of the second part.

WITNESSETH:- That the parties of these presents each in
 consideration of the undertakings, premises, and agreements on the
 part and behalf of the other herein contained have undertaken and
 agreed, and do hereby undertake and agree, the parties of the first
 part for themselves and their successors, and the party of the
 second part for himself, his heirs, executors, and administrators
 as follows:-

The Contractor in consideration of the sum of _____
 _____ dollars and _____ cents (\$ _____)
 to be paid in the manner hereinafter provided, shall and will fur-
 nish all the tools, machinery, materials and labor at his own cost
 and expense necessary or proper for the purpose of completely re-
 moving the old spans, abutments, and bents, constructing, completing
 and furnishing ready for use, the bridge across the Salt Fork Branch
 of the Vermilion River in Sidney Township, Champaign County, Sidney,
 Illinois, in full compliance with the requirements of the Engineer,
 and the plans and specifications hereunto attached.

It is also understood and agreed that the advertisement, Instruction to bidders, plans, and specifications hereto attached or hereinafter referred to, are all essential documents to this contract, and form a part thereof.

IN WITNESS WHEREOF, The parties hereto have set their hands on the date herein named. The Commissioners of Highways of the Town of _____, The County of _____ Illinois

By _____	Supervisor,	by _____	Commissioner
" _____	"	" _____	"
" _____	"	" _____	"

heretofore appointed by the direction of the Board of Supervisors to represent said County in the matter of said bridge.

Party of the first part

Party of the second part.

SPECIFICATIONS (General Clauses)

TIME OF COMMENCING.

1. The party of the second part agrees that he will commence the work herein contracted to be done within _____ days from the date of this contract; that the rate of progress of his work shall be such as in the opinion of the Engineer is necessary for completion within the time herein specified and that he will so conduct the said work that on or before _____ the whole work covered by this contract will be entirely completed.

CHARACTER OF WORKMEN.

2. The Contractor further agrees to employ only competent men to do the work; and that whenever the Engineer shall inform the Contractor in writing that any man on the work is in his opinion incompetent, unfaithful or disorderly, such man or men shall be discharged from the work and shall not again be employed on it.

PAYMENT OF WORKMEN AND OF UNPAID CLAIMS.

3. The Contractor agrees that he will pay punctually the workmen employed on the aforesaid work and the persons who shall furnish material thereunder, and will furnish the commissioners with satisfactory evidence that all persons who have done work or furnished materials under this contract have been fully paid or are not entitled to any lien under the laws of this State.

UNFORSEEN OBSTRUCTIONS AND OBSTACLES.

4. The Contractor further agrees that he will sustain all losses or damages arising from the action of the elements, the nature of the work to be done under the specifications, or from any unforeseen obstructions or encumbrances which may be encountered in the prosecution of the work. The Contractor is however, in the event of such unforeseen contingencies, entitled to such extension of time for completing the contract as may be determined by the Engineer, provided he shall have given notice in writing of the cause of the detention.

CONTRACTOR RESPONSIBLE FOR ALL WORK AND MATERIALS
PREVIOUS TO ACCEPTANCE OF THE WORK.

5. The contractor will be held responsible for any and all materials or work, and he will be required to make good at his

own cost any injury or damage which said materials or work may sustain from any source or cause whatever before final acceptance thereof.

PROTECTION OF PROPERTY AND LIVES.

6. The Contractor further agrees that he will indemnify and save harmless from all claims, suits, actions and proceedings of every name and description which may be brought against said Commissioners for or on account of any injuries or damages to persons or property received or sustained by any persons or corporations on account of the use of any improper materials or workmanship or act or omission on the part of the contractor.

CONTRACT NOT TO BE SUBLET OR ASSIGNED.

7. The Contractor further agrees that he will give personal attention constantly to the faithful prosecution of the work and will not assign or sublet the work or any part thereof.

ABANDONMENT OF WORK.

8. In the case of the Contractor's default to employ workmen, purchase tools and materials, and complete the work, or in case he abandons or unnecessarily neglects the work, said commissioners reserve the right and option to cancel this contract and relet the work or any part thereof, and said Contractor shall not be entitled to any claims for damages on account of such annulment. If the contract is relet under these conditions, and there is any increase in cost above the amount of this contract the Contractor must pay such difference in cost to the commissioners. If the amount of such new contract is less than the first contract, the Commissioners agree to pay to the Contractor such difference in

the amounts of the two contracts.

CLEANING UP.

9. When the work is completed, the surrounding grounds shall be cleaned of all rubbish caused by the construction, all sheds, etc., and left in a neat and satisfactory condition.

DEFECTIVE MATERIAL OR WORKMANSHIP.

10. Defective work or material may be condemned by the Engineer at any time before final acceptance of the work, and such defective work must immediately be rebuilt according to the plans and specifications. When defective material has been condemned, it shall be removed by the Contractor and disposed of to the satisfaction of the Engineer. In case the Contractor shall neglect or refuse to replace any defective material or work after notice has been given by the Engineer within the time designated by the Engineer, such work or material shall be replaced or removed by the Engineer at the Contractor's expense.

FOREMAN OR HEAD WORKMAN.

11. At all times when work is in progress, there shall be a foreman or head workman on the grounds and also copies of the plans and specifications. Instructions given to such foreman or head workman shall be considered as having been given to the Contractor.

FAILURE OF THE ENGINEER TO REJECT POOR WORK OR MATERIALS.

12. Failure or neglect on the part of the Engineer or any of his authorized agents to reject or condemn bad or inferior work or any materials, shall not be construed to imply an acceptance

of such work or materials if it becomes evident at any time prior to the final acceptance of the work; neither shall it be construed as barring the party of the first part at any subsequent time from the recovery of damages for such a sum of money as may be needed to build anew all portions of the work in which fraud was practiced or improper material hidden, whenever found.

ENGINEER'S DECISION BINDING ON BOTH PARTIES.

13. To avoid litigation, it is agreed by both parties to this contract that the Engineer shall act as referee in all questions arising under the terms of this contract between the parties thereto, and that the decision of the Engineer in all such cases shall be final and binding upon both parties alike.

DEFINITIONS.

14. Whenever the word "Commissioners" is used in this contract it is understood to mean the party of the first part. Whenever the word "Contractor" is used it is understood to mean the party of the second part. Whenever the word "Engineer" is used it is understood to mean H.C. Petersen, County Bridge Engineer.

CONTRACTOR'S BOND.

15. The Contractor shall be required to file a bond in a sum equal to double the amount of this contract; said bond shall be furnished by some reliable surety company approved by the State Department of Insurance and shall refer to said contract. The law requires that said contract and bond in order to be binding must be executed and filed within ten days after the date of letting or awarding of said contract.

PAYMENT.

16. Upon completion of the work according to the contract, plans and specifications, the Engineer shall make to the party of first part, a statement setting forth the work done and material furnished by the Contractor, together with the amount due the Contractor therefore, and shall certify the same in writing. The obtaining of the certificate of the Engineer as to the work done and the price thereof shall be a condition precedent to the right of the Contractor to be paid the sums due him under the terms of this contract.

SPECIFICATIONS (Special Clauses)

PLANS AND SPECIFICATIONS.

The work shall be constructed according to the plans and these specifications both of which shall be a part of the contract. They contemplate a complete structure and any error or omission in plans or specifications shall not release the Contractor from building the structure complete.

REMOVAL OF OLD STRUCTURE.

The Contractor will tear down the old structure without unnecessary damage; pile up the wooden parts; remove old bents; disconnect the steel portions, and haul the steel to Sidney, Illinois, or an equivalent haul; all to be done with the approval of the Engineer. All parts are to remain the property of Champaign County, Illinois.

LINES AND STAKES.

Before commencing excavation, it will be the duty of the Contractor to notify the Engineer who will give him center line and stakes, and the new structure shall be constructed to the lines shown upon the plan and as such, staked out by the Engineer.

EXCAVATIONS.

Excavation for foundations shall be made by the Contractor to a depth of foundation line as shown on the plans, or if compact gravel, rock, or sand is reached before, he shall notify the Engineer and do as directed by him.

COFFERDAMS.

The enclosure for all footings shall be composed of three-inch sheeting (tongue and groove) to be made watertight, and substantial and to be left permanently in place after the tops have been sawed off at the original level of the ground. The space between this sheeting and the piers or abutments is to be filled in with rip-rap.

PILING.

If it is deemed necessary by the Engineer to drive foundation piles, the foundation piles shall be of sound white or burr oak having a minimum diameter of eight inches at the smaller end. They shall be driven to refusal under the weight of a 2,500-pound hammer falling thru a distance of twenty feet or the equivalent in work units if a steam hammer is used. An iron cap collar shall be provided to keep the top of the pile from splitting. Six inches of piles are to project into the concrete.

GRADING.

A six-inch layer of earth is to be placed on the floor of the bridge for its entire length. The approaches are to be graded up to the top of this earth cushion.

SPECIFICATIONS FOR CONCRETE MASONRY.

PLANS AND DIMENSIONS.

All concrete masonry shall be built to the dimensions as shown on the plans furnished or approved by the Engineer and which are a part of these specifications.

The concrete shall be of the character as indicated on the plans or as provided for in these specifications and shall be built by the Contractor in accordance therewith.

CONCRETE.

CEMENT. Some standard brand of Portland cement shall be used which has been in practical use on public works for not less than five years and shall have proved satisfactory therein. No brand of cement shall be used which the Engineer deems unfit for the work nor shall any cement be used which fails to give satisfactory results according to the standard methods of testing as provided by the American Society for Testing Materials. The Contractor shall provide sufficient means to protect the cement against dampness, and no cement shall be used which has become caked.

The Contractor shall notify the Engineer in writing what brand or brands he intends to use and before ordering the cement shall receive the written approval of the Engineer as to the brand selected. It is understood that such approval merely covers the

selection of the brand; that the cement itself may be rejected if it fails to meet the requirements herein specified.

SAND. Sand shall consist of coarse, clean, sharp quartz grains and shall not contain over two per cent of clay or loam.

STONE. Stone used for concrete work shall be broken to the sizes herein specified, and shall consist of clean, sound material. No weathered or disintegrated material shall be used.

WATER. Clean water shall be used in mixing and building concrete.

CLASS A. and B. Unless otherwise specially indicated on the plans, there will be two classes of concrete known as Class A and Class B.

Class A. concrete shall consist of 1 part cement, 2 1/2 parts sand and 4 parts rock broken to pieces which will be retained on a 3/8 inch screen and which will pass a 1 inch ring.

Class B. concrete shall consist of 1 part cement, 3 parts sand, and 5 parts rock broken to pieces which will be retained on a 3/4 inch screen and which will pass a 2 1/2 inch ring.

GRAVEL. Gravel may be used in the place of broken stone and sand for concrete and when so used shall conform to the following requirements:-

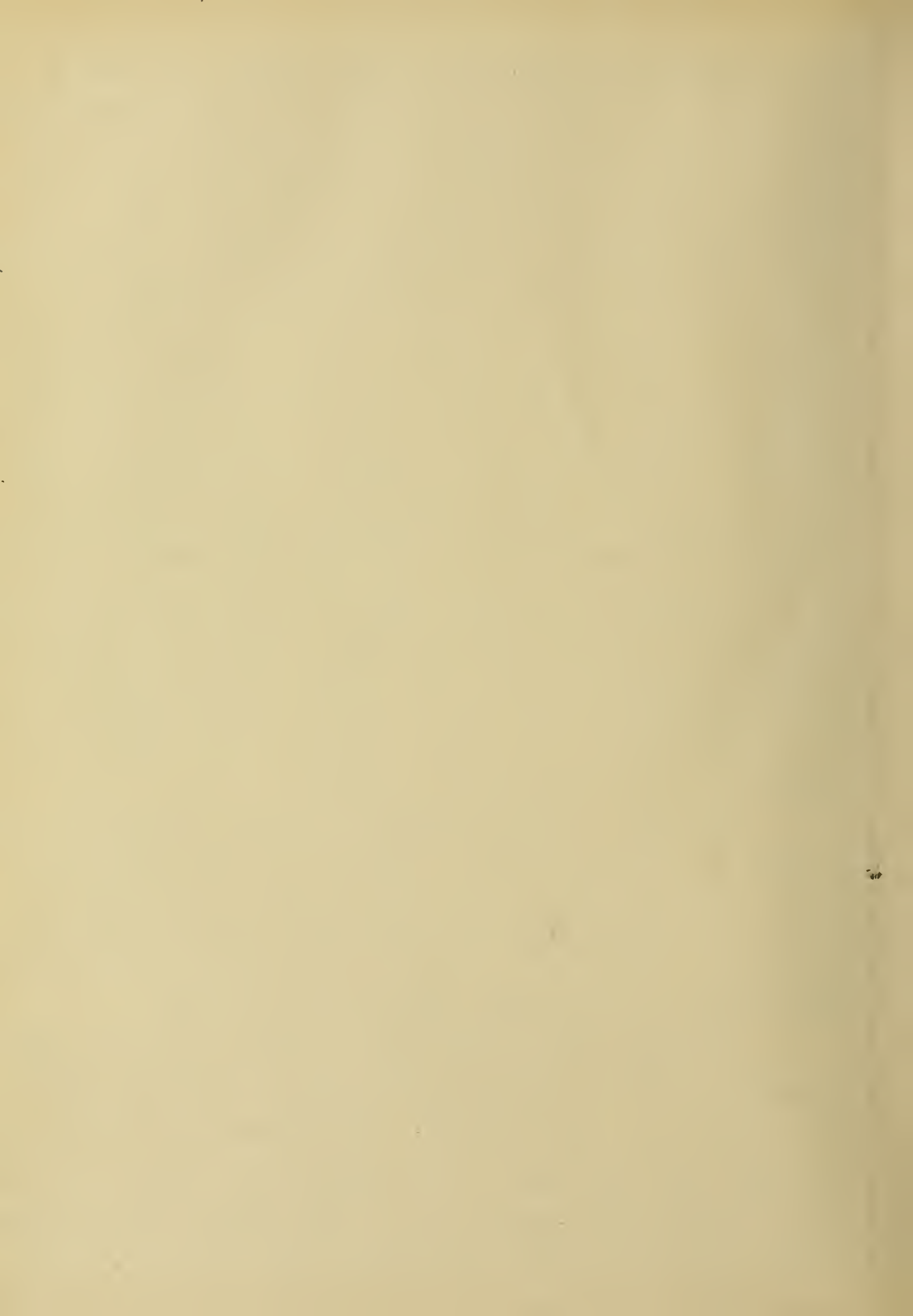
Gravel used for concrete shall consist of clean, hard and sound stones, pebbles and sand, having a reasonably uniform gradation from the coarsest material allowable for the work specified to fine sand, and shall be used and proportioned in the following manner:-

In proportioning gravel concrete, frequent tests will be

made to determine the proportion of sand to stone. For class A gravel concrete all material which passes a $1/4$ inch screen will be considered sand, and all material which is retained on a $1/4$ inch screen and passes a 1 inch screen will be considered stone. For class B gravel concrete, all material which passes a $1/4$ inch screen will be considered sand and all material which is retained on a $1/4$ inch screen and passes a $2\ 1/2$ inch screen will be considered stone. For any of the above named classes of concrete, should the volume of sand so found be less than 60 per cent of the volume of stone, sufficient sand shall be added to bring up the proportion of sand to stone to 60 per cent. Should the volume of sand be more than 60 per cent of the volume of stone, sufficient stone shall be added to reduce the proportion of sand to stone to 60 per cent or sufficient cement shall be added so that the volume of cement to sand shall be for Class A concrete as 1 to $2\ 1/2$; and for class B concrete as 1 to 3. In any case the proportion of cement to sand shall be as stated for the various classes of concrete.

MOULDING. Moulding having $3/4$ inch or 1 inch sides shall be used in all exposed corners. The surface of such moulding in contact with the concrete, may be rounded to a uniform radius or may be flat. In the latter case the resulting angles between adjacent surfaces in the finished concrete shall be equal.

BEVELLED FACES. Forms shall be given a bevel of 1 inch to 1 foot, wherever projections of the concrete, such as copings, floor-beams, etc., would otherwise cause binding upon removal of the forms. The pitch shall be so arranged as to increase the thickness of copings, floor-beams, etc., at the base and narrowest parts of such projections shall have dimensions not less than as shown



on the plans.

MIXING. Concrete may be mixed by machinery or by hand.

If by machinery, the mixing shall be done in a batch mixer, approved by the Engineer. If by hand, the sand and cement shall be first mixed dry in proper proportions until the mixture shows a uniform color; to the mixture thus prepared shall be added the proper proportion of broken rock which has been previously drenched with water, and the whole shall be mixed until every piece of the rock is coated with mortar. Sufficient water shall be used in mixing the concrete so that the water will readily flush to the surface with very light tamping or troweling.

Concrete shall be mixed in such quantities that a batch can be placed in the work within forty-five minutes from the time of mixing. No concrete shall be used which has taken an initial set and which requires retempering.

If mixed by hand, all mortar and concrete shall be mixed on a tight board or other platform approved by the Engineer.

PLACING. All concrete shall be carefully deposited in place in such a manner that the stone and mortar are not separated.

As fast as concrete is put in place, it shall be thoroughly tamped and the portion next to the forms shall be troweled by using a spade or other means to bring the mortar in thorough contact with the forms.

Concrete shall be placed in continuous horizontal layers in walls and girders. In floors the concrete shall be placed for the full thickness and the construction floor carried along in this manner.

FORMS. The Contractor shall provide all necessary material

and means for building the necessary forms for all concrete masonry.

All forms shall be constructed as to be held rigidly in place. If at any point of the work, after the concrete has been placed, the forms show signs of bulging or sagging, that portion of the concrete shall be immediately removed on notice of the Inspector and the forms shall be properly supported. The amount of concrete to be removed shall be determined by the Inspector, and no extra allowance shall be made to the Contractor for such work.

All forms are to remain in place until in the opinion of the Engineer it is safe to remove them.

It is understood that all prices for concrete masonry shall include furnishing all materials, necessary forms and false work, tools, machinery, labor, excavation and incidental work necessary properly to place the concrete.

JOINTS. If the work is interrupted, so that the last layer of concrete is deposited more than twenty-four hours before the next can be laid, and there are no reinforcing rods projecting, a timber 8 inches wide shall be laid the entire length of the course and shall be bedded for at least 4 inches in the concrete and allowed to remain until the concrete has set. When the work of laying concrete is again resumed, the timber shall be removed, and the surface of the concrete shall be cleaned and washed with neat cement paste; and then the new concrete shall be placed immediately upon the surface thus prepared.

FINISH. The forms covering what will be the exposed face of the concrete masonry shall be removed as soon as the Engineer decides that it is safe to do so, and all crevices neatly filled with a stiff 1 to 2 cement mortar thoroughly rammed into place.

The whole surface is then to receive a wash of neat cement paste, the same to be kept moist and protected from wind and sun to prevent drying until the cement is thoroughly set. The cement wash shall be put on the last thing at night unless other treatment is specified.

All exposed faces shall be so finished that they will have a smooth and neat appearance.

All top surfaces such as the top of retaining walls, abutments, girders, floors, etc., shall be treated by tamping and troweling in such a manner as to flush the mortar to the surface and provide a smooth, even surface, free from pits or porous places.

If necessary to secure such a surface, a thin layer of mortar consisting of one part of cement to two parts of sand shall be applied evenly and troweled smooth before the concrete has set.

The exposed surfaces of concrete copings, side rails, and arch rings where so indicated on the drawings, shall be bush-hammered so as to give a roughened surface of uniform appearance, and if required by the Engineer shall be washed with a paste of neat cement.

ABUTMENTS AND WING WALLS. Unless otherwise specified, Class B concrete shall be used in all plain concrete abutments and wing walls, and shall also be used elsewhere as may be provided for on the plans or by the written directions of the Engineer.

REINFORCED CONCRETE. All reinforced concrete, and all plain concrete masonry measuring less than six inches in thickness, shall be made of Class A concrete unless otherwise shown on the drawings or directed in writing by the Engineer.

STEEL FOR REINFORCED CONCRETE. Unless otherwise shown on the drawings, all steel for reinforcement in concrete shall consist of bars which shall be twisted square section bars or which shall otherwise provide for some means of rigid mechanical bond at frequent intervals.

Plain bars will be permitted only where shown on the drawings, or as may be specially directed in writing by the Engineer.

The size of all steel reinforcement as indicated on the drawings is the side of a square equivalent to the required net section.

The steel bars shall be distributed in the concrete in the exact positions and have the net sectional area provided in the drawings.

Unless otherwise specified, all steel for reinforced concrete shall be medium steel with an elastic limit of not less than 32,000 lbs. per square inch. Steel bars shall withstand bending cold with a radius equal to twice their diameter through 180 degrees without fracture.

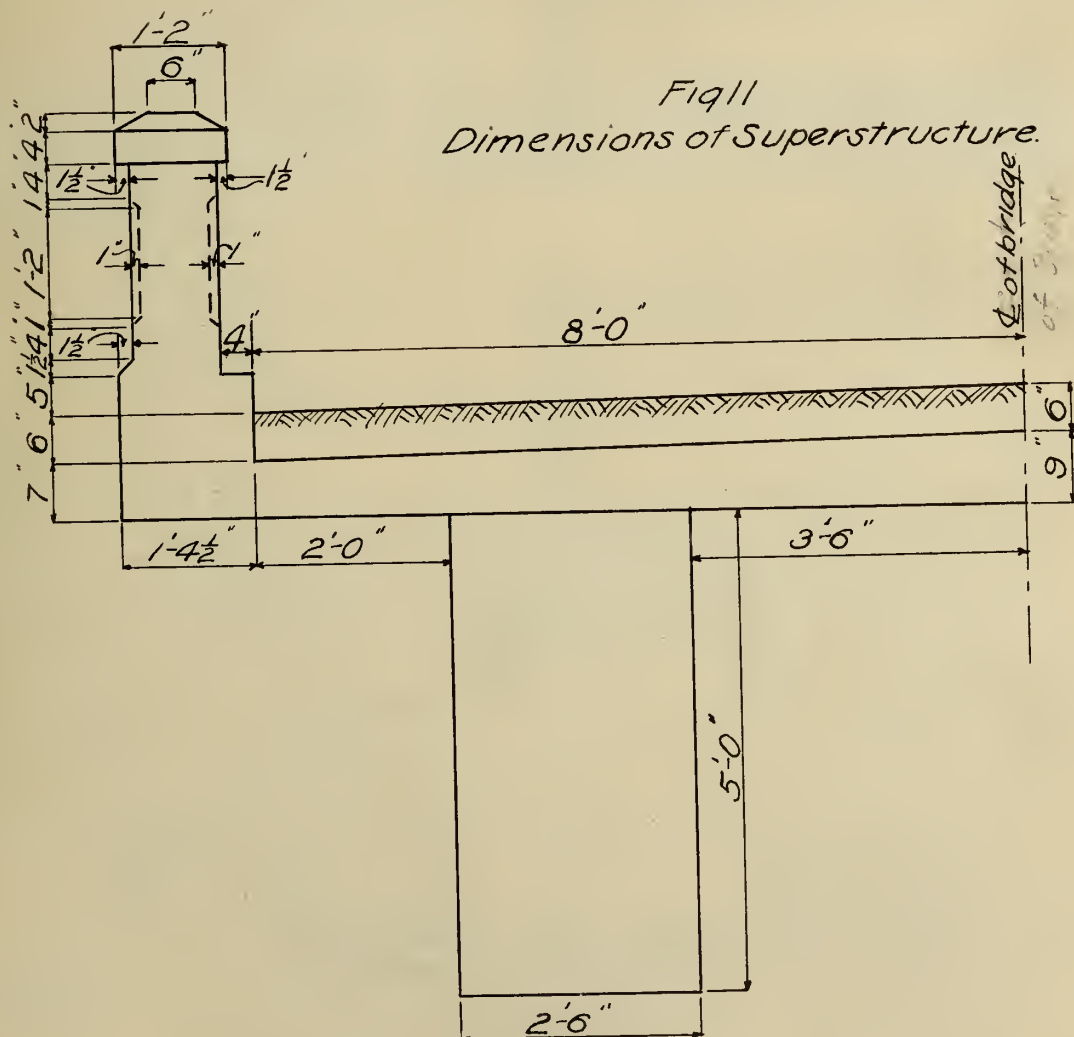
Before steel is placed in the concrete, it shall be free from grease, dirt or rust, and the Contractor shall provide means on the work for properly cleaning the steel.

Special care shall be exercised to insure contact of the concrete with every portion of the surface of the steel reinforcement.

The general outlines of this bridge resemble those of the Ryan Bridge which was designed by the Illinois Highway Commission. The design will be taken up under the following headings. (1) Design of girders, (2) design of floor slab, (3) design of abutments and piers. In all cases the bending moments were determined first, after which the amount of steel was calculated. Assumptions as to dimensions and allowable stresses will be noted. As far as possible sketches will be drawn to eliminate descriptive matter.

Art. 7. Design of Superstructure.

Design of Girder. The general outlines of the section are shown in Fig. 11 with dimensions as given in plans for the Ryan Bridge.



The dead load weight per foot of one girder will first be determined and the following assumptions are made. The weight of reinforced concrete = 150 lbs. per cu. ft. The weight of earth cushion (saturated loam) 110 lbs. per cubic foot. The maximum live load on the girder will occur when a 15 ton engine takes the positions shown in Fig. 12 and 13.

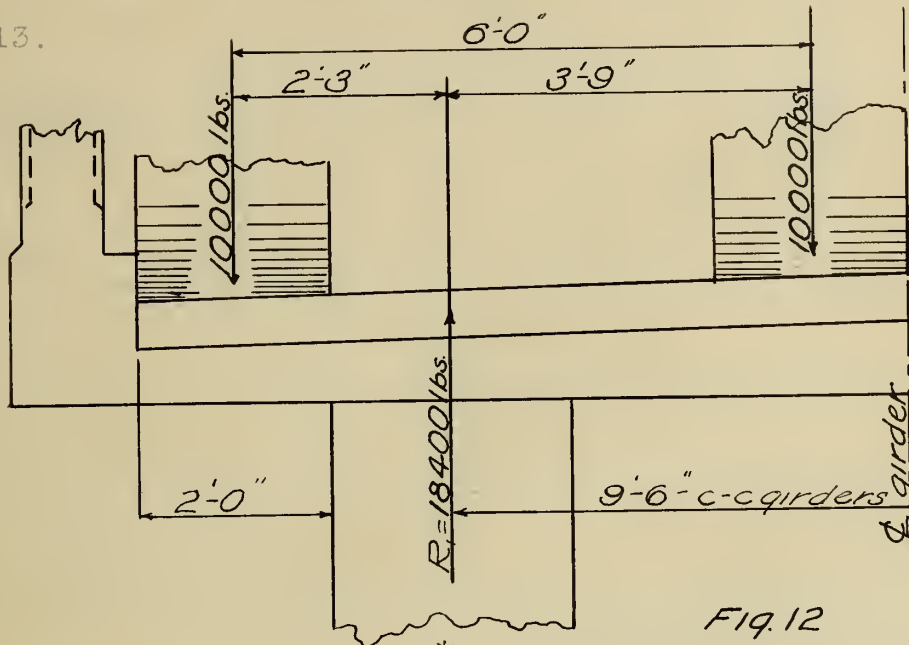


Fig. 12

Position of wheels for
Maximum Load on Girders.

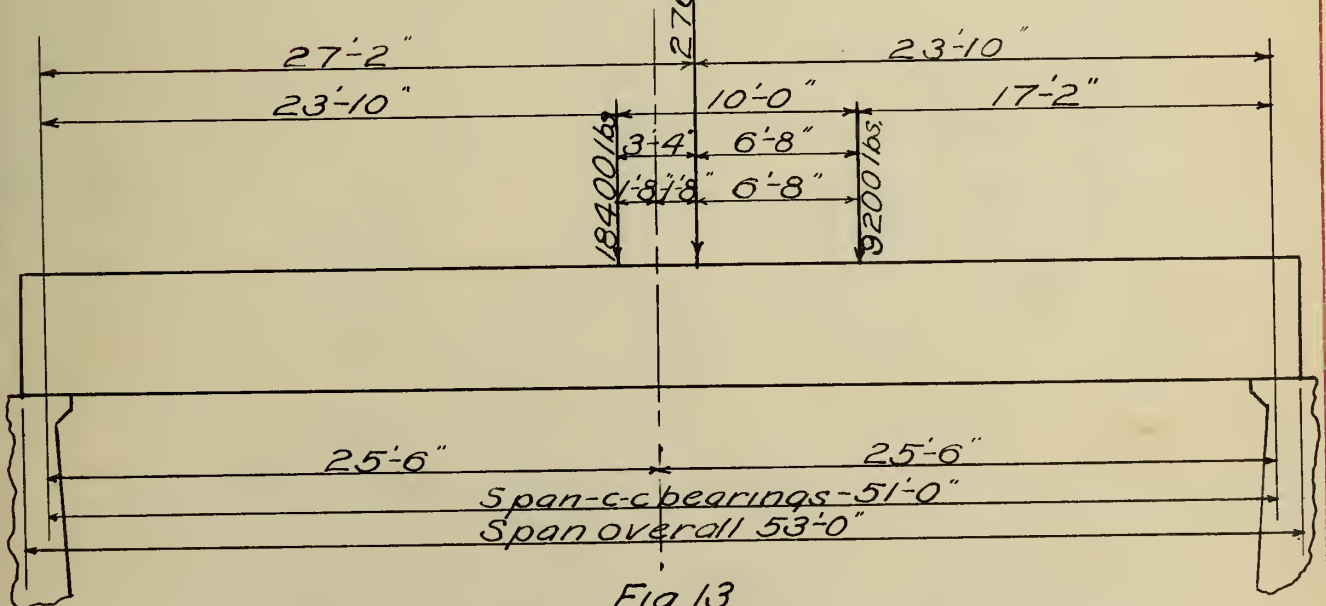


Fig. 13

Position of wheels for Maximum Moment.

Determination of Dead Load Weight per foot of Girder.

Area of railing = $(6" \times 14") + 2(11" \times 5") + (9" \times 15.5") + (19" \times 16.5") = 647.5 \text{ sq. in.}$

$$\text{Wt. per ft. of railing} = \frac{647.5}{144} \times 1 \times 150 = 675 \text{ lbs.}$$

$$\text{" " " " floor slab} = \frac{6" \times 9"}{2 \times 12"} \times 8' \times 150 = 750 \text{ "}$$

$$\text{" " " " Girder} = 4.75' \times 2.5' \times 150 = 1,780 \text{ "}$$

$$\text{" " " " Earth Cushion} = 110 \times .5' \times 8' = 440 \text{ "}$$

$$\text{Total Dead load weight per ft. of girder} = \frac{3,645}{\text{ "}}$$

Let R_1 , Fig. 12, = the reaction which comes to the left girder due to the rear engine wheels when placed as shown.

Let R_2 equal the load due to the forward wheels.

Taking moments about the middle of the right hand girder we have:

$$R_1 \times 9.5 - 10,000 \times 11.75 - 10,000 \times 5.75 = 0$$

$$R_1 = \frac{117,500 + 57,500}{9.5} = 18,400 \text{ lbs.}$$

Since the forward wheels carry 5,000 lbs., $1/2$ that which the rear wheels carry,

$$R_2 = \frac{18,400}{2} = 9,200 \text{ lbs.}$$

Let R_3 = Reaction due to live load. (Fig. 13.)

Let R_4 = Reaction due to dead load.

The line drawn between the two wheel loads represents their resultant and it equals 27,600 lbs. Taking moments about the center of support on the right we have,

$$R_3 = \frac{27,600 \times 23.83}{51} = 12,900 \text{ lbs.}$$

$$R_4 = \frac{51}{2} \times 3645 = 93,000$$

$$\text{Total Reaction} = 105,900$$

Let M = max. moment in lb. inch, which occurs under the heavier wheel load.

$$M = (105,900 \times 23.83 - 23.83 \times 3645 \times \frac{23.83}{2})12.$$

$$M = (2,520,000 - 1,035,000)12 = 17,800,000\#"$$

Recent tests made by the University of Illinois Experiment Station indicate that in the combined floor and girder type of construction, a considerable portion of the floor slab acts with the upper portion of the girder in taking compression. This requires, however, that the floor slab and most of the girder be poured at one time. In other words the results of the tests hold true only where the slab and girders are monolithic. It is very doubtful if the contractor to whom this work may be let can pour sufficient concrete at one time to make the slab and girders monolithic. Hence, the floor slab will not be considered in designing the girder.

It will not be wise to make the girder any deeper than 5 feet as it will protrude too far into the water at times of flood. The depth of the girder will therefore be limited to 5' - 0". With this depth and the great bending moment which we have the stresses in the concrete will probably be a great deal higher than the allowable working stress. Double reinforcing will therefore be resorted to. The curves for double reinforcing given on Plate II of Brooks' Reinforced-Concrete will be used. The nomenclature will be the same as that given in the various texts on Reinforced Concrete, and which has come into general use.

Assume dimensions as shown in Fig. 14 also.

$$f_s = 16,000\#/\text{sq. in.}$$

$$f_c = 800\#/\text{sq. in.}$$

$$n = 15$$

1880

1881

1882

1883

1884

1885

1886

1887

1888

1889

1890

1891

We have given

$$M = 17,800,000 \text{ in}^2$$

$$d = 50"$$

$$b = 30"$$

From the text.

$$r = \frac{f_s}{f_c} = \frac{16,800}{900} = 20$$

$$N_2 = \frac{M}{b d f_c} = \frac{17,800,000}{30 \times 50 \times 50 \times 800} = 0.297$$

With $r = 20$, and $N_2 = 0.297$, we get from the curves,

$$p = 0.0164$$

$$p' = 0.0095$$

$$A_s = p b d = .0165 \times 30 \times 50 = 24.60 \text{ in}^2$$

$$A'_s = p' b d = .0095 \times 30 \times 50 = 14.25 \text{ in}^2$$

The area of 15 - 1 1/4" bars = 24.60." These will be used for tensile reinforcement.

The area of 10 - 1 1/4" bars = 15.62." These will be used for compressive reinforce.

Design of Stirrups and Bent up Bars.

The reinforcement for the web stresses were determined by a graphical method given in Turneaure and Maurer page 226. The results will be shown in Fig. 15.

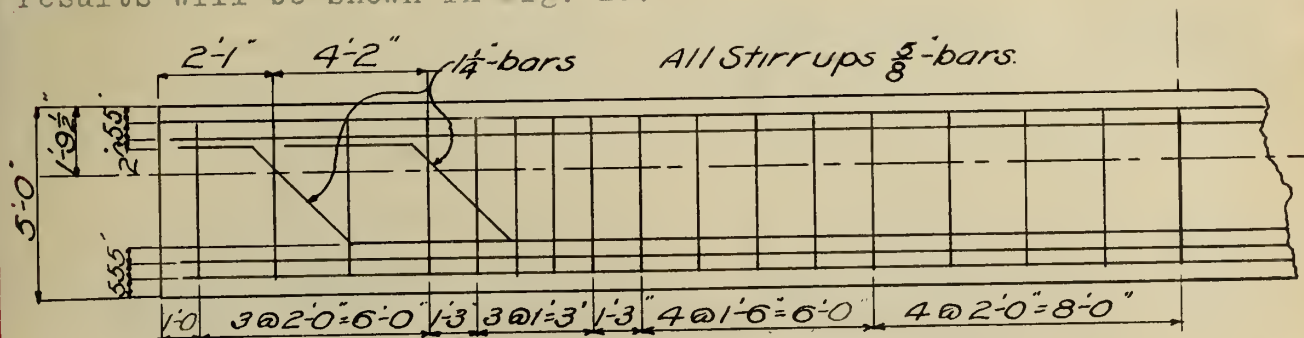


Fig. 15-Web Reinforcement.

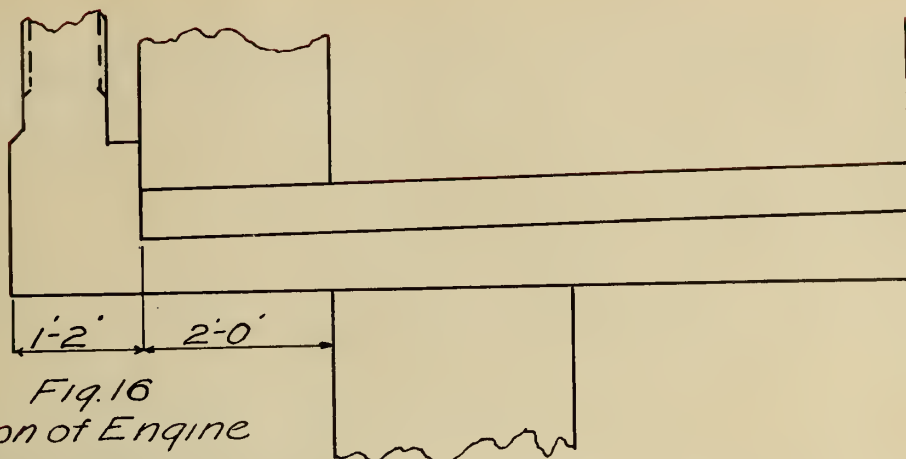


Fig. 16
Position of Engine
Wheel for Maximum
Moment in Cantilever Floor Slab

The maximum moment will occur at the outside edge of the girder when the slab is loaded as shown in Fig. 16 and the slab will be designed as a simple beam one foot wide.

It is a well known fact that concentrated loads do not act at a point but are distributed over a certain area. An assumption must be made as to what this area actually is. In this case it will be assumed that the concentrated wheel load is distributed for a distance of 3 feet in front and in back of the center of the wheel.

The equivalent uniform load is therefore $\frac{10,000}{2 \times 6} = 800$.

The loadings are shown diagrammatically in Fig. 17.

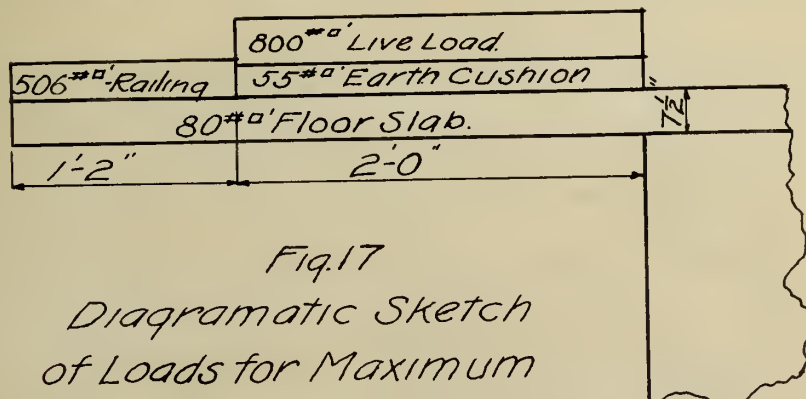
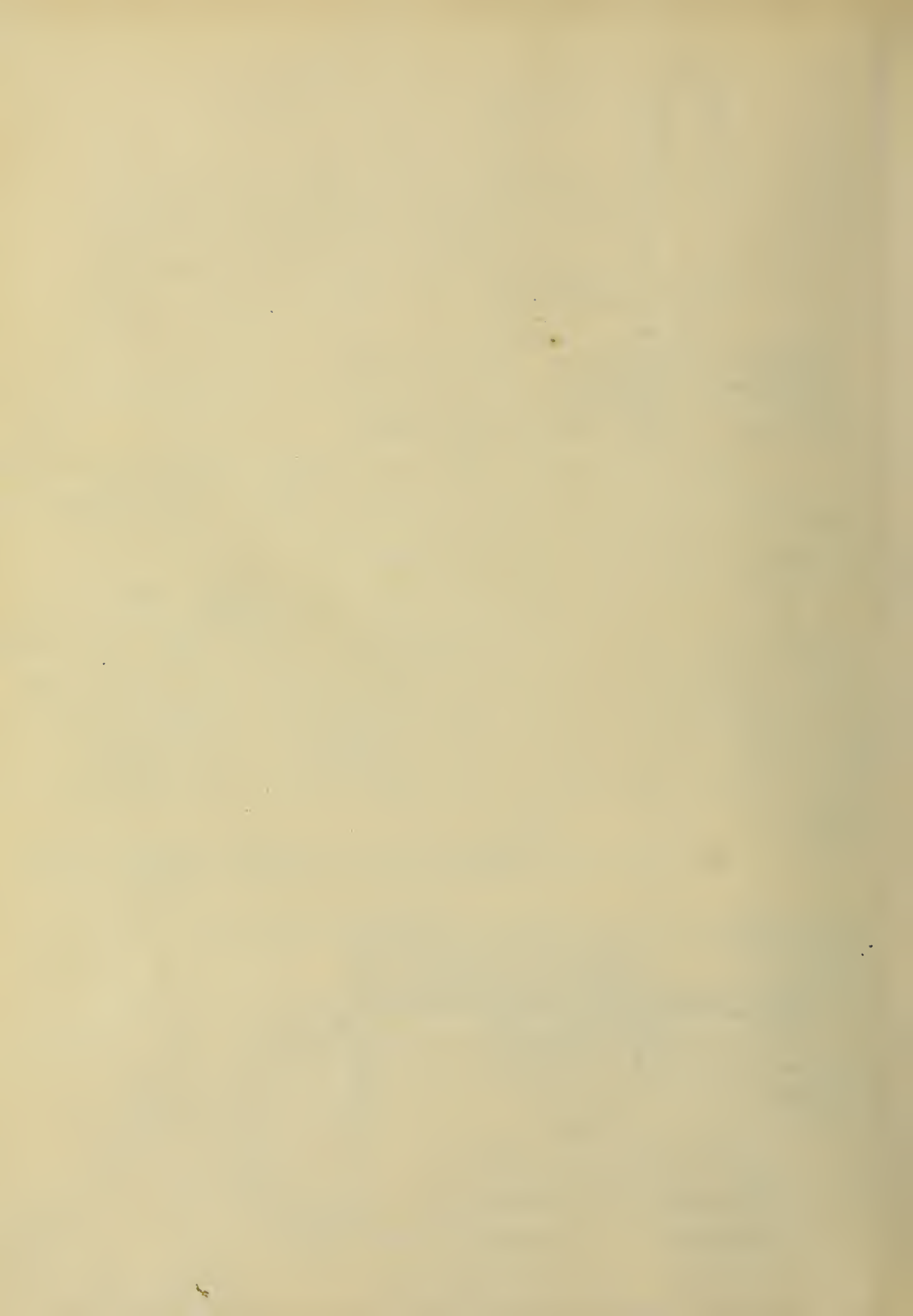


Fig. 17
Diagrammatic Sketch
of Loads for Maximum
Moment in Cantilever Floor Slab

b = 12"
f_s = 18,000
f_c = ?
n = 15
m = ?
d = 6"
r = ?



Since the tension in the cantilever is in the upper portion of the slab, the reinforcing will be placed at the top. In practice it is placed about $1\frac{1}{2}$ " from the outside edge of the slab. Therefore d will be $7\frac{1}{2}" - 1\frac{1}{2}" = 6"$.

Taking moments about the left edge of the girder

$$M = (586 \times 1.33 \times 2.66) + (935 \times 2 \times 1) \times 12$$

$$M = (2080 + 1870)12 = 47,400 \text{ ft-lb}$$

From Curves Turneaure and Maurer page 277.

$$R = \frac{M}{bd^2} = \frac{47,400}{12 \times 6 \times 6} = 112.5$$

$$p = 0.56\%, f_c = 675$$

$$A_s = p b d = .0056 \times 12 \times 6 = 0.403 \text{ sq in}$$

$5/8"$ bar - 11 inches on centers gives 0.45 sq in of steel per foot of slab. The slab will now be investigated to determine if the value of d equals -6 inches is great enough.

$$d = \sqrt{\frac{M}{b R^2}} = \sqrt{\frac{47,400}{12 \times 121}} = 5\frac{3}{4}" \text{. Therefore a } d \text{ of } 6" \text{ is great enough.}$$

The total shear at the outside edge of the girder equals

$$675 + 1,600 + 270 + 110 = 2,655 \text{ lbs.}$$

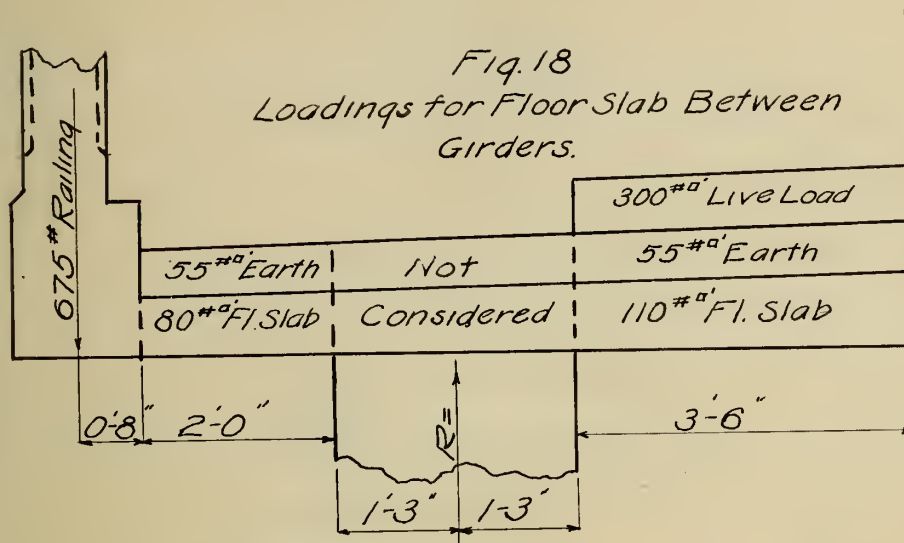
$$\text{The Unit shear equals } \frac{2,655}{12 \times 6} = 37 \text{ lbs. per sq. in.}$$

This is so small that the slab will need no reinforcement for shear.

Assuming that the allowable bond stress is 80 lbs. per sq. in., a bar must theoretically be imbedded in the concrete a length of 50 diameters $= 50 \times 5/8" = 31\frac{1}{4}$ inches. However, since there is negative moment over the girders an additional length of bar for bond will be required; the bars will therefore extend across the width of the bridge.

Design of portion of floor slab between Girders.

The equivalent uniform live load for a fifteen ton engine is assumed by many designers to be 300 lbs. per sq. ft., and this value will be used. Fig. 18 shows diagrammatically the loadings.



Let R equal the reaction at the center of the girder due to the loading shown in Fig. 18.

$$\text{Then } R = 675 + 2 \times 135 + 3.5 \times 465$$

$$R = 675 + 270 + 1627 = 2,572$$

Since the slab is symmetrically loaded the max. moment in the slab between the girders occurs at the center line of the bridge.

$$M = (+2572 \times 4.75 - 675 \times 8.66 - 270 \times 7 - 465 \times 3.5 \times 1.75)12$$

$$M = (+12,250 - 5,840 - 1,890 - 2,850)12 = 1,670 \times 12$$

$$M = 20,000 \text{ in.}$$

$$d = 9" - 1 \frac{1}{2} = 7 \frac{1}{2}"$$

$$b = 12"$$

$$f_s = 16000$$

$$R = \frac{M}{bd^2} = \frac{20,000}{12 \times 7.5^2} = 29.7$$

$$f_c = 300$$

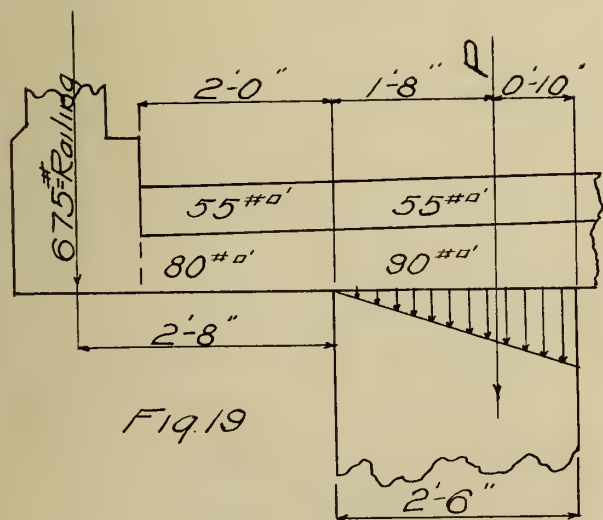
$\rho = 0.2, 0$

$$\Delta s = p b d = .002 \times 12 \times 7.5 = 0.18" \text{ per ft.}$$

5/8" bars spaced 5" on centers give an area of 0.19 ^{sq}" per ft.

Theoretically the above design is correct, but practically it is wrong for the following reason. It is a well known fact that when fresh concrete is poured upon a concrete surface, even tho the latter has already set, there will be more or less adhesion between the freshly poured concrete and the older concrete when the former begins to harden. There will therefore be adhesion between the floor slab and the girder since the latter will be poured first. It will be proved in the following mathematical demonstration that this adhesive force between the girder and floor slab need be very small in order that it alone may hold in equilibrium the railing and the cantilever floor slab and that therefore the moment at the middle of the bridge due to the railing and cantilevered floor slab may be neglected.

The adhesive forces will vary from zero at the left edge of the girder to a maximum at the right edge as represented in Fig. 19 by the triangle. Let R equal the resultant of these forces acting at the center of gravity of the triangle namely 10 in. from the right edge of the girder. Taking moments about the left edge of the girder



we have for equilibrium,

$$P \times 1.66 \quad 145 \times 1.25 - 675 \times 2.66 - 135 \times 1.0 = 0$$

$$P = \frac{1,795}{1.66} \frac{135 - 181}{1.66} = \frac{1749}{1.66} = 1,050$$

This force is distributed over an area 12" wide since a 1 ft. section of slab was assumed 2' - 6" long. The average unit adhesive forces is therefore $\frac{1050}{20 \times 12} = 2.92$ lbs. The maximum unit adhesive forces is twice the average or 5.84 lbs. Since the adhesion between concrete has been proven by experiments to run well above the maximum value found, the effect of the moment at the middle of the bridge due to the cantilevered slab and railing will be neglected in the design of the slab between the girders.

Referring again to Fig. 18, the maximum moment occurs at the middle of the bridge and it is equal to $1/8 l^2$.

$$M = \frac{(300 \quad 55 \quad 110)}{8} \times 7 \times 7 \times 12 = 34,200 \text{ #"}^2$$

$$d = 9" - 1 \frac{1}{2}" = 7 \frac{1}{2}"$$

$$b = 12"$$

$$f_s = 16,000 \text{ #"}^2$$

$$R = \frac{M}{bd^2} = \frac{34,200}{12 \times 7.5^2} = 50.6$$

$$p = 0.35$$

$$A_s = p b d = 0.0035 \times 12 \times 7.5 = 0.315 \text{ #"}^2$$

One half inch bars spaced 9 1/2 inches on centers give an area of 0.32 # per ft.

$$\text{The maximum shear} = 3.5 \times 465 = 1,627$$

$$\text{The unit shear} = \frac{1,627}{8 \times 12} = 17 \text{ lbs. per sq. in.}$$

As the concrete is able to carry this shear no reinforcement for shear is necessary.

$$\text{The required length of bar for bond} = 50 \times 1/2 = 25 \text{ inches.}$$

For convenience the bars should be run up to the girders.

To prevent cracks in the concrete due to temperature and contraction in setting, the slab and railing must be provided with longitudinal reinforcement. In order to determine the amount of this reinforcement a value of p equal to 0.5% is generally assumed. This will require one half inch bars spaced 12 in. on centers in the floor slab and in the railing.

Art. 8. Design of Substructure.

Abutments. At the time the bridge site was surveyed test borings were made under the old bridge on each side of the river with a 1 1/2-inch carpenter's augre fitted with 1/2 inch gas pipe coupled in five foot sections. The results of these borings indicated the existence of a stratum of blue clay about 25 feet below the level of the floor of the old bridge. To make certain that the footings rest on this blue clay the elevation of the bottom of the footings was taken at 71.5 or 28 1/2 feet below the floor of the old bridge.

The design of a reinforced concrete abutment logically divides itself into the following parts. First the determination of the dimensions with reference to stability. Second the design of the vertical wall, and third the design of the footings. Since there should be no vertical tension in the footings, the resultant of the forces acting on the abutment must fall within the middle third of the base. With this in mind several trials were made and it was found that an abutment of dimensions shown in Fig. met with these requirements. The problem therefore resolves itself into investigating this abutment for stability and proportioning the steel.

The vertical forces are the dead load weight of the bridge, the live load on the bridge and the weight of the abutments. The loads coming to the abutment due to the dead load weight of one span of the bridge is equal to $3645 \times 2 \times \frac{53}{2} = 193,500$. The load coming to the abutment due to live load on the bridge is equal to $85 \times 16 \times \frac{53}{2} = 36,000$ making a total of 229,500 lbs. coming to the

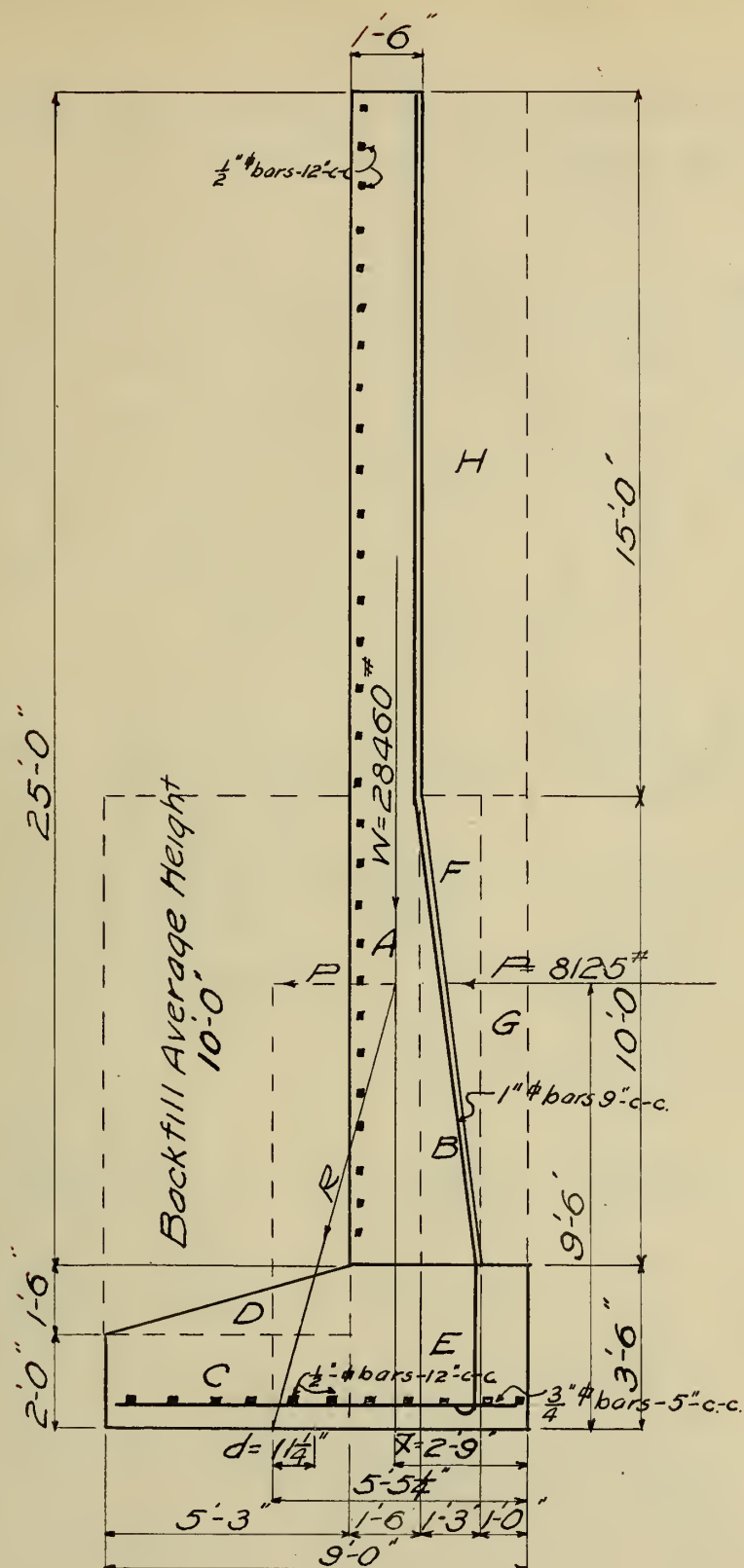


Fig. 20
Section of Abutment.

abutment. Since the abutment will be as long as the overall width of the bridge or 18' - 8", the load per foot of abutment equals

$$\frac{229,500}{18.66} = 12,250 \text{ lbs.}$$

The weight of the abutment acts at its center of gravity the calculations for which are shown in the table. The weight of the earth back of the abutment acts at its center of gravity as is also shown in the Table IV. Moments were taken about the lower right hand edge of the footing.

TABLE IV (See Fig. 20)

Reference Number	Area	Distance of cent. of grav. from Rt. edge of footing.	Weight	Moment about Rt. edge of footing	Distance of cent. of grav. of total Wt. from Rt. edge of footing.
Abutment					
A	37.50	3' - 0"	5,625	16,900	
B	6.25	1' - 10"	937.5	1,720	
C	10.50	6' - 5 1/2"	1,575.0	10,100	
D	4.0	5' - 6"	600.0	3,300	
E	13.12	1' - 10 1/2"	1,970.	3,690	
			<u>10,707.5</u>	<u>35,710</u>	5.33'
Earth back of Abutment					
F	6.25	1' - 5"	687.5	974	
G	10.00	0' - 6"	1,100.0	550	
H	33.75	1' - 1 1/2"	3,715.0	4,180	
			<u>5,502.5</u>	<u>5,704</u>	1.035

The loads coming on the abutments from the bridge act at the center of the upper portion of the vertical wall namely at a distance of 3 feet from the right edge of the footing. Let \bar{X} equal the

distance of the center of gravity of all the vertical forces from the right edge of the footing. Then taking moments about the right edge of the abutment we get

$$\bar{X} = \frac{12,250 \times 3 + 10,707 \times 3.53 + 5,502 \times 1.035}{12,250 + 10,707.5 + 5,502.5}$$

$$= 2.75$$

The horizontal forces acting on the abutment are those due to the earth pressure. It will be assumed that the earth acts as a liquid whose weight is 20 lbs. per cu. ft. The total pressure will therefore be equal to $\frac{1}{2} p h^2$ and it will act at a distance of one third of the height of the abutment above the base. This pressure is:

$$P = \frac{1}{2} \times 20 \times 28.5^2$$

$$= 3,125 \text{ lbs.}$$

The intersection of the resultant of all the forces will therefore be equal to $2.75 + \frac{3,125}{28,460} \times 9.5 = 2.75 + 2.69 = 5.44'$ from the right edge of the abutment.

The maximum pressure at the heel and toe is given by the formula $P = \frac{W}{l} + \frac{6 W d}{l^2}$, where W is sum of the vertical forces, d , the distance from the middle of the base to the resultant, and l the length of base. Therefore the pressure at the toe is

$$P = \frac{28,460}{9} + \frac{6 \times 28,360 \times .94}{81}$$

$$= 3,160 \quad 1,980$$

$$= 5,140 \text{ lbs. sq. ft.}$$

The pressure at the heel equals $31,60 - 1,980 = 1,180 \text{ lbs.}$

The abutment was investigated for the condition when the earth is replaced to a height of 10 feet in front of the wall and it was found that the pressure at the toe was 5,300 and at the heel

2,500 pounds per square foot.

Design of the Vertical Wall.

The maximum moment will occur at the top of the footing and it is equal to $8,125 \times 6 \times 12 = 585,000$

assume $d = (2' - 9") - 2" = 2' - 7"$ and since b is 12, therefore:

$$\begin{aligned} R &= \frac{M}{bd^2} \\ &= \frac{585,000}{12 \times 31 \times 31} \\ &= 50.7 \end{aligned}$$

If $f_s = 16,000$ then $f_c = 400$ and $p = 0.35$ per cent and the area of the steel is

$$\begin{aligned} A_s &= p d b \\ &= 0.0035 \times 12 \times 31 \\ &= 1.31 \text{ " per foot.} \end{aligned}$$

This is given by 1"-bars spaced 9" on centers, their area being 1.33 " per ft.

Design of the Footings.

The maximum moment in the footing will occur as a result of the upward pressure of the earth and it will be located at the left edge of the vertical wall. The center of gravity of the vertical forces to the left of the wall lies at a distance of 2.9' from it. The average pressure is equal to 4,100 lbs. The maximum moment therefore is $4,100 \times 5.25 \times 2.8 \times 12 = 222,000 \text{ "}$. In case piles are driven they will extend a distance of six inches into the concrete. Therefore $d = (3' - 6") - 6" = 36 \text{ inches}$, and since b is 12"

$$\begin{aligned}
 R &= \frac{M}{bd^2} \\
 &= \frac{722,200}{12 \times 36^2} \\
 &= 46.4
 \end{aligned}$$

If $f_s = 16,000$, then $f_c = 400$, and p is 0.31 %, and the area of the steel is:

$$\begin{aligned}
 A_s &= p b d \\
 &= .0031 \times 12 \times 36 \\
 &= 1.340" \text{ per foot.}
 \end{aligned}$$

This is given by 3/4" bars spaced 5" on centers.

Design of the Wing Wall

Earth highway embankments are generally built on a slope of two to one. The tops of the wing walls will therefore be built to this slope to a point four feet above the ground. As the front wall will slope back from the face of the abutment at an angle of 30 degrees, the wing walls must necessarily be twenty three feet long to meet with these requirements, since the elevation of the ground is 86 at a point 23 feet from the side of the bridge. The cross section of the wing walls will be the same throughout as that of abutment. The steel in the wing walls and footings will be determined by designing a section at the abutment and at the end of the wall, the steel being distributed uniformly between the two sections. As this design does not differ essentially from that already given it will not be shown here but the results will be indicated in Fig. 21.

Because of the nature of the topography on the north side of the bridge, wing walls will be of very little benefit and will not be used.

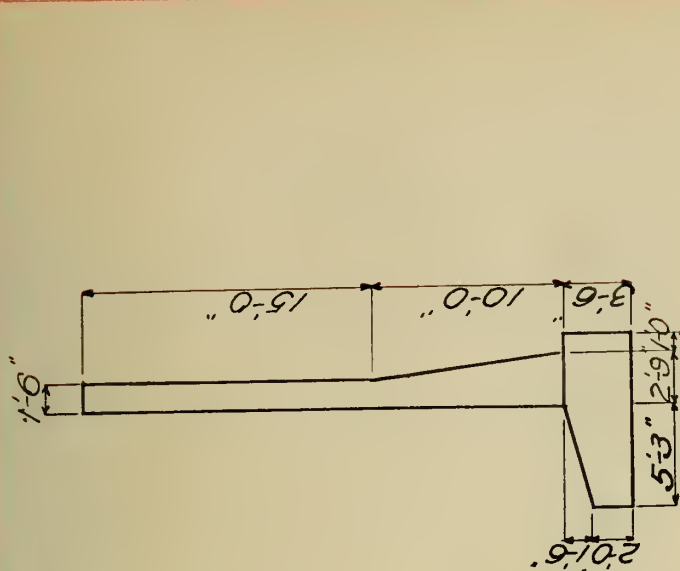
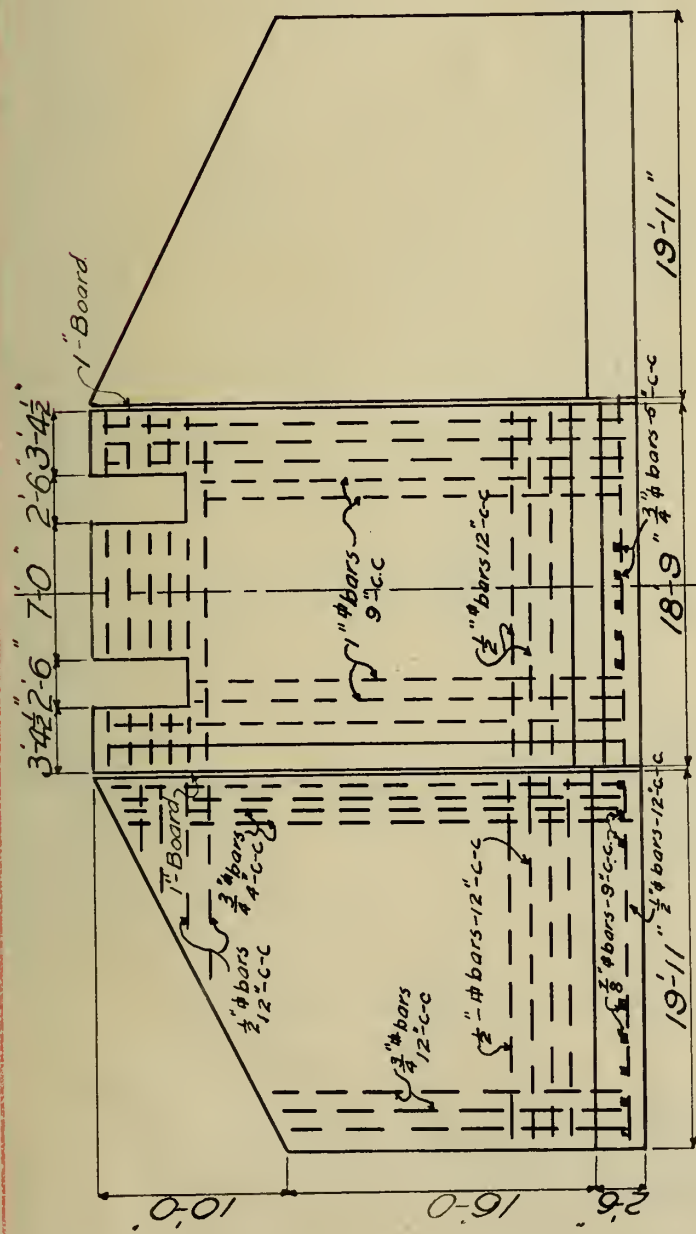
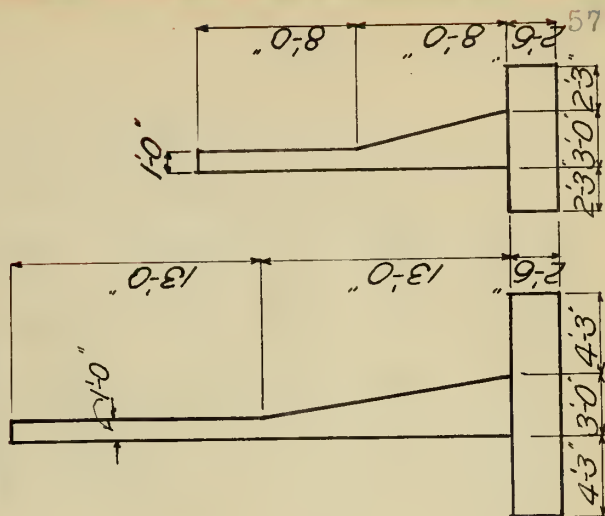
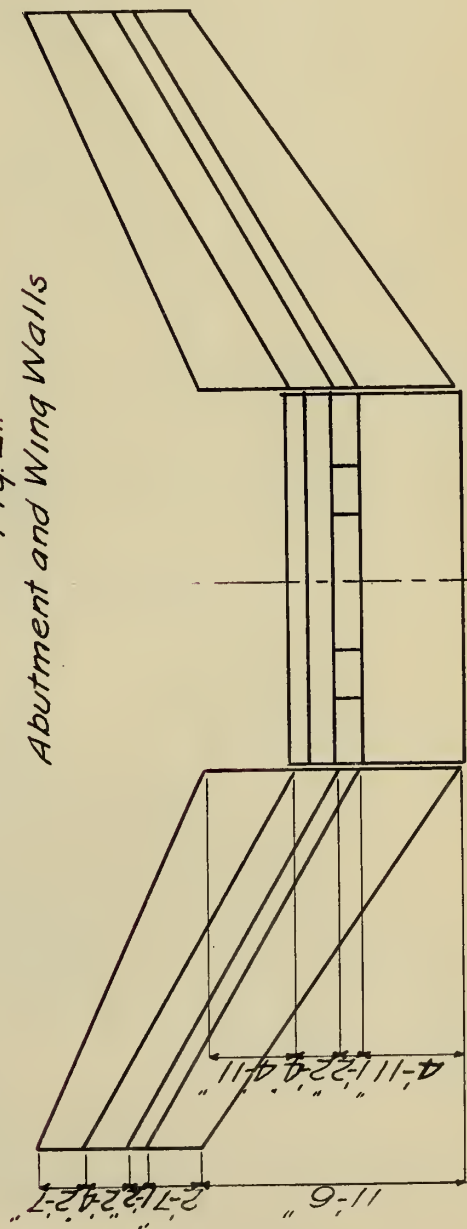


Fig. 21.
Abutment and Wing Walls



Design of the Piers.

The design of the piers involves the determination of certain dimensions not already fixed, from a practical standpoint rather than from a theoretical one. For instance, the ends of the piers should not be built at right angles to the sides but they should consist of two planes built at an angle of about forty five degrees with the sides, meeting in a line, the purpose of which is to cut the water and avoid scour. The sides and ends should be built on a batter of preferably one inch in one foot; and the footings should extend sufficiently beyond the walls to distribute the load so that the pressures on the soil will not be excessive. The bottom of the footing will be placed at an elevation of 71.5; and since the girder is five feet deep the elevation of the top of the footing is 95. The footing must at least be 4' wide on top and 12' long not including the ends. If the sides are built on a 1:12 batter, the dimensions will be 4,150 lbs. The maximum moment in the footings

$$= \frac{1}{8} W l^2$$

$$= \frac{4150 \times 9 \times 9 \times 12}{8}$$

$$= 505,000$$

d is again 36", and since b is 12

$$R = \frac{505,000}{12 \times 36 \times 36}$$

$$= 32.5$$

If f s is 16,000, then $f_c = 300$ and $p = 0.22\%$, and the area of the steel is

$$A_s = p b d$$

$$= 0.0022 \times 12 \times 36$$

$$= 0.325 \text{ in}^2$$

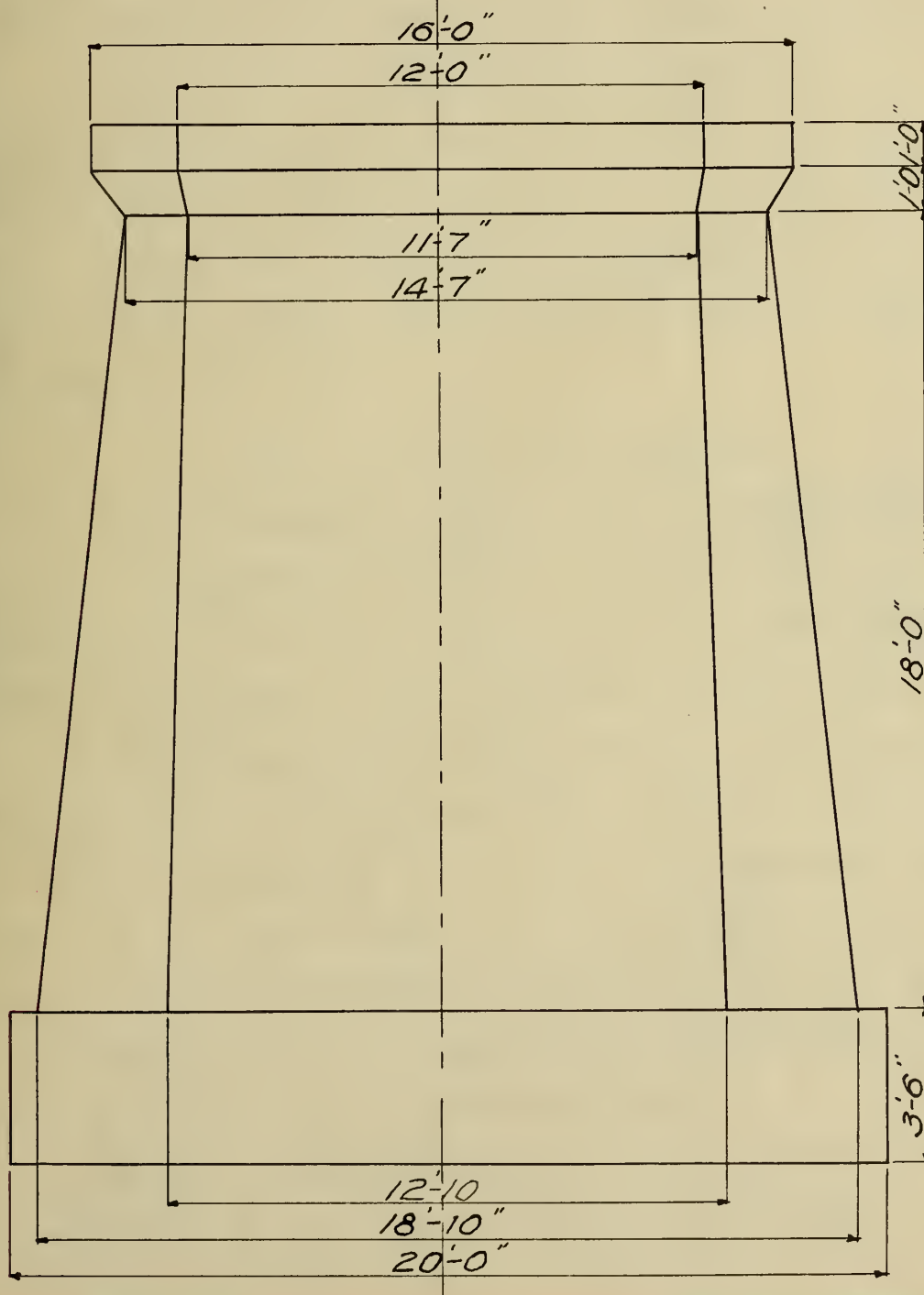
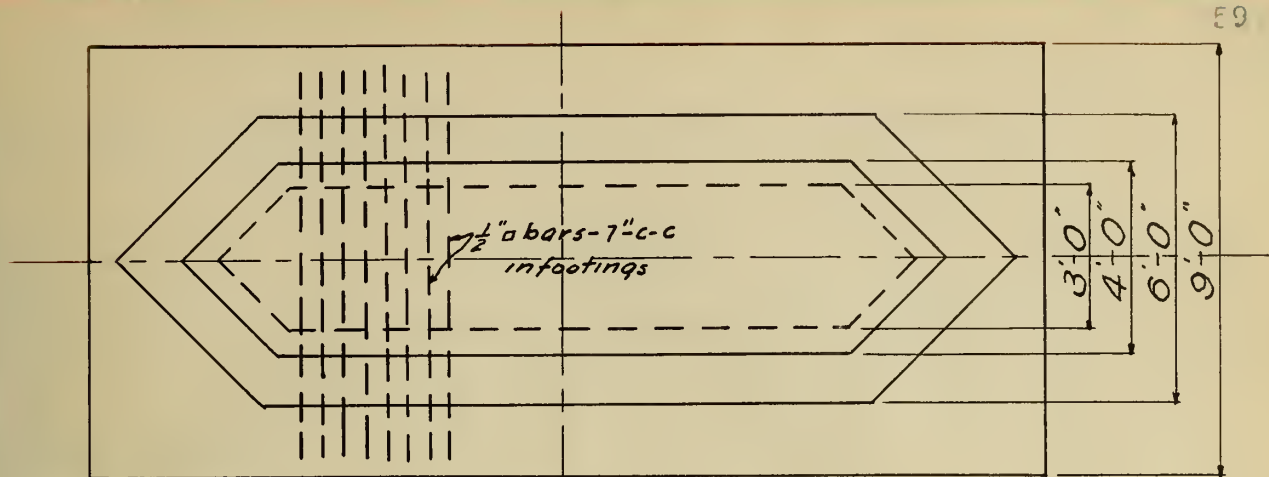


Fig 22
Piers

This area is given by $3/4$ " bars spaced 7" on centers.

IV. COST.

Art. 9. Cost of Removing Old Structure.

To arrive at the cost of removing the old bridge, Messrs. Bresee and Brown, contractors, Mattoon, Illinois, were addressed and data was submitted by them whereby it was calculated that the cost of removing spans of the parabolic type was \$1.65 per foot. However, since the approach spans are comparatively easy to remove, it was thought that a price of \$1.50 per foot of span for the whole bridge is a fair one. The cost of removing the old bridge is therefore $160 \times \$1.50 = \240 . Allowing ten dollars for incidentals would make the cost \$250.00.

Art. 10. Cost of New Structure.

Cost estimating is perhaps one of the most difficult branches of engineering with which an engineer should familiarize himself; and it is only thru experience and the exercise of good judgment that success in cost estimating can be attained.

It is the purpose of this article to determine the cost of this bridge which it is hoped will closely approximate the actual cost. The determinations of the cost of any structure naturally divides into two parts, namely the cost of the materials and the cost of the labor; the former can be arrived at quite accurately, while the latter is only an approximation based on the cost of labor in the erection of similar structures.

Since the quantity of steel varies greatly in the superstructure piers and footing, it will be more accurate to determine

the cost of these parts separately, which was done by estimating the cost of one yard of concrete and then multiplying by the total number of yards. The cost of materials is based on the following current prices as obtained from a local dealer:

Cement,	\$1.60 per bbl.
Sand,	1.35 per yd.
Stone,	1.70 per yd.
Steel,	2.00 per 100 lbs. at Pittsburg warehouses.

The cost of mixing and placing concrete, and building forms is based on cost data given in the Twenty-fifth Annual Report of the Illinois Society of Engineers and Surveyors, for a great number of bridges built in Illinois by the Highway Commission. It was thought that an average of the values given there would give a fair price. The cost of placing and bending steel was taken at two cents per pound which is a value taken from "Engineering and Contracting". The item of \$0.75 per yard for haulage is based on the assumption that a team costs \$5.00 per day, that ten trips can be made in a day and that a yard of sand or stone can be hauled to the load. This amounts to \$0.50 per yard of sand or stone but as the cement and steel would require the hauling of the equivalent of an additional half yard, \$0.75 was thought sufficient to cover the total haulage of a yard of concrete. Dry and wet excavation are taken at \$0.40 and \$0.60 per cubic yard. These are average prices given in "Engineering and Contracting". The present price of lumber is \$53.00 per M.F.B.M. upon which the cost of the sheeting and bracing of the coffer dams was based. The cost of the labor for placing sheeting and bracing is based upon the experience of the writer as a time and cost keeper for a construction company. The cost of the bridge is tabulated in Table

Art. 11. Total Cost.

	Cement per yd. of Concrete	Sand per yd. of Concrete	Stone per yd. of Concrete	Steel in place at $\frac{1}{4}$ lb. of per lb. Conc.	Haul per yd. of Conc.	Mixing and placing Conc.	Forms per yd. of Conc.	Cost of Concrete per yd.	Total yards of Conc.	Total Cost
Superstruct.	1.46*2.34°	0.51*0.69°	0.82*1.40°	184*7.36°	.75	1.15	1.70	15.59	262.5	4039.88
Abutments-2 Wings-2	"	"	"	90 3.60	"	"	1.25	11.18	110.0	1229.80
Piers-2	"	"	"	---	"	"	1.10	8.00	96.25	770.00
Footings	1.22 1.95	0.52 0.70	0.86 1.46	44 1.76	"	"	---	8.00	120.0	960.00
Excav. Class A								0.40	206.0	82.40
Excav. Class B								0.60	254.0	152.40
Cofferdams	14,000 yds of Lumb.	at 53.00 per M								463.98
Lumber Haulage										5.00
Grading	120 yds.	at 35¢ per yd.								42.00
Labor (Cofferdam)	2 carpenters	at \$3.00 per day								67.50
	3 laborers	at \$2.50 per day								250.00
Removing old spans										8062.96
* Quantity								Eng. profit etc. 20% of cost		1612.59
o Cost								Total Cost of Bridge		\$9675.55

V. LETTING OF THE BRIDGE.

Art. 12. Advertising and Township Notices.

It is of special importance in the letting of any contract to secure bids from contractors from as wide a range of territory as possible, because it stimulates competition, and produces the best results. In order to anticipate this the advertisements given in connection with the contract and specifications should be inserted in the leading Engineering periodicals such as Engineering News, Engineering Record, and Engineering and Contracting, as well as in the local newspapers. The advertisement should according to law also be printed on a card to be posted thruout the township and county for the benefit of the local residents.

Art. 13. The Letting.

At the time specified all bids which are properly addressed, should be opened and read in public by some official such as the County Clerk. The successful bidder and the amount of his bid should be made public in as short a time as possible after the reading. It is preferable that the names of all the bidders together with the amounts of their bid be made public as it may prove of interest to the people of the community.

Art. 14. The Bids.

In general the contract should be awarded to the lowest bidder, but not without consideration of the amount of his bid. The engineer's estimate is a fair indication of what the bridge will cost and if the lowest bid is very much less than the engineer's estimate it should be rejected. For instance, should the lowest bid be \$6000 which is \$3500 less than the engineer's estimate, it

can at once be assumed that the contractor has made an error or else expects to do a very inferior grade of work and use poor materials. If the contract were let at this price a great deal of trouble would be experienced in trying to make the contractor live up to the specifications. On the other hand, if the lowest bid was \$12,000 it can at once be seen that this price is exorbitant and all bids should be rejected. In addition to this, care must be exercised not to award the contract to an incompetent man.

VI. DISCUSSION AND CONCLUSION.

In comparing the cost of this bridge with that of a steel bridge it was found that the concrete bridge is the cheaper by about \$3000. In view of this and the permanency and beauty of a concrete bridge there is no doubt but what a concrete bridge is the most desirable for this location.

Altho it has been mentioned that the Ryan bridge was used as a model or guide for this design, the reader should not be led to believe that this design is a copy of the former, as in no case do the two designs check each other. This is probably due to the fact that designing is not an exact science but is governed largely by experience, opinion and good judgment. As an illustration of this it was learned that the Illinois State Highway Commission used an allowable stress of 1000 lbs. per square inch compression in the concrete and designed the girders as simple beams. The writer satisfied himself by a mathematical investigation that this is justifiable provided that the floor slab and girders are monolithic, as the actual extreme fibre stress under these conditions is only about 500 lbs. per square inch. However, since there was a difference of opinion as to practical construction, the girders were designed as

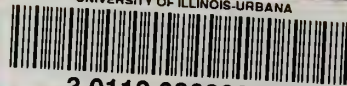
simple beams with double reinforcement.

The writer has given his best efforts, a great many times at a sacrifice to his other work in order that this thesis may prove of practical value, and altho the latter may not have been accomplished, it is felt that the benefits derived from being required to use his own judgment and responsibility should prove to be of no little value to him.





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